APPENDIX O

Marine Biological Considerations

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Supplement prepared by Jeffrey B. Graham, February 2010

Marine Biological Considerations Related to the Reverse Osmosis Desalination Project at the Applied Energy Sources Huntington Beach Generation Station.

3 August, 2004

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Marine Biological Considerations Related to the Reverse Osmosis Desalination Project at the Applied Energy Sources Huntington Beach Generation Station

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Executive Summary

Plans are underway to construct and operate a reverse osmosis (RO) desalination plant adjacent to the Huntington Beach Power Generating Station (HBGS). The HBGS uses ocean water for the once-through cooling of its steam condenser units. The seawater intake is positioned in the Pacific Ocean approximately 1,840 ft offshore from the mean high tide line. After circuiting through the condensers, the heated seawater exits through a discharge pipe that opens to the ocean 1,500 ft offshore.

The proposed Huntington Beach desalination facility will convert a fraction of the HBGS's cooling-seawater return flow into freshwater. Approximately 100 million gallons per day (mgd) of the heated seawater (i.e., after it has passed through the condensers) will enter the RO system. From this about 50 mgd of freshwater will be produced, forming in the process about 50 mgd of approximately twice-concentrated (2x) seawater. This 2x seawater will be returned to the cooling seawater outflow

downstream of the RO diversion point where it will become diluted during passage to the offshore discharge site.

The average ocean salinity at Huntington Beach and over a vast expanse of ocean area around it is 33.5‰ (parts per thousand). Addition of the RO discharge stream to the HBGS's heated outflow will slightly elevate ocean salinity within a small area. This report analyzes the extent of this salinity increase and determines what if any effect it may have on the marine organisms living near the discharge.

The marine organisms living along the Huntington Beach coastline and adjacent areas are part of a biologically and climatologically unique ecological region called the Southern California Bight (SCB). The SCB is an open embayment extending from Point Conception, CA into Baja California, Mexico and 125 miles offshore. Biologically, the SCB is a transition-zone species assemblage located between two larger and diverse biological provinces, one in the cooler waters to the north and the other in the warmer waters to the south. SCB organisms comprise a mix of species, some from the cooler, northern- and some from the warmer, southern- regions.

Physical, biological, and oceanographic factors all affect the total biomass of the SCB and cause year-to-year variation in the number of species occurring both within the SCB and in the waters around the HBGS. Ocean temperature, current patterns, and upwelling, for example, all affect ocean nutrient levels and food supplies, which are fundamental requirements for an ecosystem. In addition, the arrival of planktonic animals to coastal areas and biological variables such as recruitment (seasonal addition of young-of-the-year organisms to a population) and both habitat availability and quality determine ecosystem-species composition, diversity, and biomass. The young stages of most marine plants, invertebrates, and fishes living in coastal waters at Huntington Beach and throughout the SCB begin life as drifting plankton. The survival of these young to their next life stage requires that the appropriate and vacant habitat be encountered at the critical time during their drifting life phase when transformation to a sub-adult takes place. Thus, evaluation of either local or regional habitats with respect to their biodiversity or the abundances of different types of organisms as well as their ages, body sizes, and growth rates must always be made in the context of the large-scale factors influencing them, whether along the Huntington Beach coastline or throughout the entire SCB.

The discharge of heated seawater by the HBGS has been a necessary and permanent coastal oceanographic feature since power generation began. The heated water mixes with the receiving water, forming a mainly surface-occurring discharge plume that fans out and, depending upon both the HBGS's total water flow-rate and oceanographic conditions, drifts south with the prevailing surface current while gradually cooling back to ambient seawater temperature.

The NPDES (National Pollutant Discharge Elimination System) permit issued by the Regional Water Quality Control Board governing cooling-water discharge by the HBGS requires procedures to protect receiving-water organisms, such as limiting the temperature difference between discharge water and ocean water (delta T). Also required are regular environmental monitoring and biological surveys to verify that there are minimal thermal effects associated with the discharge. Since the early 1970s MBC Applied Environmental Sciences, Costa Mesa, CA has conducted regular biological assessments of the area around HBGS. These involve comparative surveys of infaunal, macroinvertebrate, and fish abundances in habitats that are adjacent to the HBGS discharge and more remote from it. The analyses show that the organisms present in these habitats as well as their spatial and temporal variations in abundance are both directly comparable to other similar areas in the SCB and that the thermal discharge from HBGS is not adversely affecting the surrounding marine community.

Dr. Scott Jenkins Consulting employed computer models to describe the dispersion and dilution of the combined discharge from the Huntington Beach RO desalination facility and the HBGS into the receiving waters. The most important variable in the model is the HBGS's cooling-water flow rate, which defines the "in-pipe-dilution ratio" of the 2x concentrated RO seawater. This ratio is calculated as:

$$\frac{\text{Total HBGS Flow} - \text{RO Water Flow}}{\text{RO Concentrate Return Water Return}}$$

The 20-year (1980-2000) operational history of the HBGS's total cooling-water flow is best described by a bimodal flow distribution. That is, there are two flow levels, one averaging 126.7 mgd, and the other averaging 253.4 mgd, each accounting for about 50% of HBGS operation time. (Rounding these flows to the nearest whole number gives 127 and 253 mgd and these values are used throughout the report.) The "in-pipe-dilution ratio" for a 50 mgd RO production rate at a 253 mgd total flow is (253 – 100) / 50 = 3.06. The ratio for 127 mgd is (127 – 100) / 50 = 0.54.

By affecting density differences between the discharge and receiving water, the HBGS delta T (temperature difference between the discharge and ambient seawater) will also affect the combined discharge dispersal.

Historically, the HBGS has operated with a delta T of 10°C and models were run using this value.

Also modeled was a delta T of zero; that is, when HBGS is pumping water but not producing power (i.e., this models operating the RO facility at times when there is no power production). This will potentially affect the combined discharge dispersal because outflow having an elevated salinity but the same temperature as the receiving water will have a greater density difference than discharge water that is both heated and more saline.

The third modeling variable is the mixing potential of the receiving water, which is determined by factors affecting coastal ocean conditions such as water temperature and salinity, water level, tides and tidal currents, wave height and wind speed. A computer search of 20-year time-series records (1980-2000) determined long-term averages for interactive coastal ocean conditions and modeling was done using two receiving-water mixing states, "average or normal" and "sub-optimal." The "sub-optimal" receiving-water mixing conditions are the result of the simultaneous co-occurrence and persistence of a suite of coastal oceanographic factors and wind conditions that reduce vertical water movement. This co-occurrence is infrequent and periods of "sub-optimal" receiving-water mixing are both rare and brief.

The HBGS seawater discharge site is 1,500 ft offshore in about 28 ft of water. The discharge opening faces upward and is about 10-15 ft below the water surface. The upward force of the discharge flow is sufficient to broach the water surface and form a boil that increases mixing with ambient water. From its central core (i.e., at the discharge pipe), this boil expands outward, entraining and mixing the surrounding ocean surface water with the HBGS discharge water.

Jenkins' dispersal model analyses, which have been validated independently, show that the addition of RO salinity to the HBGS discharge will have a greater density, causing it to sink faster than does the heated-only flow return. Maps of discharge dispersal along the coastline show that an area of increased salinity in both surface and bottom waters will form around the discharge and extend downcoast, gradually equilibrating with ambient salinity (33.5°/oo). The highest salinities will occur at the discharge itself and the extent of the area in which salinity is elevated above ambient will vary depending on HBGS flow rate and receiving water mixing conditions. Because the combined discharge water is denser and will sink, higher salinity contours will extend further along the bottom than in the water column (i.e., there will be a salt wedge at depth).

Total HBGS flow rate has a major effect on the depth-averaged and bottom salinities within about 150 m of the discharge. For a 127 mgd flow rate, the highest depth-averaged salinity (55°/oo at the core) is reduced to 39°/oo at a distance of 150 m. Corresponding bottom salinities for the 127 mgd flow are: core 48°/oo, 150 m 37°/oo. For the 253 mgd flow, depth-averaged salinity is 42°/oo at the core and 35°/oo at 150 m. Corresponding bottom salinities for 253 mgd are: core 39°/oo, 150 m 35°/oo.

At distances beyond 150 m, mixing between the discharge and the receiving waters is sufficient to remove nearly all flow-rate-induced differences in salinity contours.

HBGS flow models that incorporated a delta T = 0 (to simulate generating station standby conditions) into the 127 mgd outflow distribution show only very slight increase in salinity (about +1°/oo) over the entire dispersal field. Thus, operating in the standby mode will not markedly affect dispersal pattern from that predicted for operation at normal delta T values. In addition, historical data shows that this operating mode occurs less than 1% of the time.

The models used by Dr. Jenkins show that the combined RO and heated discharge will establish a permanent zone around the discharge pipe in which salinity will be constantly above ambient, although variable. The size of this zone and its salinity will be inversely affected by HBGS flow rate. The highest core salinities ($55^{\circ}/_{oo}$ depth-averaged, $48^{\circ}/_{oo}$ on the bottom) will occur at the 127 mgd flow. These salinities, however, are rapidly diluted by mixing with the ambient water and, at a distance of 150 m, the depth-averaged and bottom salinities are $39^{\circ}/_{oo}$ and $37^{\circ}/_{oo}$ respectively. At a flow of 253 mgd, core depth-averaged salinity is $42^{\circ}/_{oo}$ and bottom salinity is $39^{\circ}/_{oo}$. At 150 m, both the depth-averaged and bottom salinities are $35^{\circ}/_{oo}$.

A suite of biological facts support the conclusion that the slight increases in salinity modeled for the combined thermal and RO discharge will not be large enough to have a significant biological impact on the marine species or communities living near the HBGS. With respect to temperature, the thermal increase currently experienced by the marine organisms living near the HBGS discharge is not affecting them and the dispersion models show that operation of the combined RO and HBGS discharge will favor heat loss and thus lessen the thermal excess experienced by organisms in the seawater return area.

Most of the marine organisms living near the HBGS also occur in areas of the SCB and beyond it where salinities can be greater than those that will occur in the combined RO and HBGS discharge field. For example, the natural geographic distributions of most of the species living at Huntington

Beach extend south to near the tip of Baja California where both coastal temperatures and salinities are as high or higher than those predicted for most areas in the combined discharge field. In addition, some of these species, or ones very closely related to them live in the upper part of the Gulf of California where salinities are 36-38°/oo and can be as high as 40°/oo. Thus, many of the species present in waters around Huntington Beach naturally experience a salinity range comparable to or greater than what is predicted for the combined discharge area.

Dr Jenkins' dispersal models for the 127 and 253 mgd flows show that an elevated salinity zone will occur around the discharge core and that all organisms living within these areas will encounter it. For the animals swimming in the water (some macroinvertebrates, fishes, turtles, mammals) the duration of their elevated salinity exposure will depend on their location and their residence time in the zone. Assuming, conservatively, that a fish or squid about 6 inches long has an average swimming speed of about 0.17 mph (i.e., about one-half of its body length/second), then this animal would require about 2.0 hours to swim across the center (i.e., maximum distance) of the 127 mgd salinity zone (about 600 m = 0.35 miles). Half of this swimming-time would be in salinities less than 39°/oo, and the total time of exposure to salinities above 43°/oo would be about 1 hour. A larger fish or squid would swim much faster, as would both a turtle or dolphin, which are much larger. Such a brief exposure time would have no effect on marine mammals, turtles, or most fishes which are good osmoregulators, and, while most fishes are unlikely to prefer salinities this high, comparative data showing fish easily tolerate high salinities for short periods (i.e., adverse effects of >40°/oo require exposure times of 24 hours or longer) suggest these salinities could be tolerated for a short time. Also, fishes would have the ability to "sense" such a marked salinity change in the water and could thus alter their swimming direction to avoid it.

In the case of organisms that drift across the elevated salinity areas, models developed for the discharge flow field show that a planktonic animal drifting through the discharge area would experience elevated salinity for variable times. These times would depend upon both the area of the zone and the organism's rate of drift and its position relative to the discharge core. The models show that exposure to the inner core, where salinity is highest, would be for an hour or less. Plankton drifting through the core's periphery would experience lower salinities for 2-3 hours and longer times would be spent in salinities only slightly above ambient.

While plankton, fishes, and other water-column residents would have relatively brief exposures to the highest salinities within the elevated salinity zone, this would not be the case for the benthic organisms occurring in the discharge area. Bottom-dwelling organisms living near the core would experience a salinity of between 48^{o}/oo (at 127 mgd) and 39^{o}/oo (253 mgd). Under both these flow scenarios salinity decreases abruptly with distance, dropping to 37^{o}/oo at 150 m (127 mgd) flow and to 36^{o}/oo at 50 m (253 mgd).

While comprehensive salinity tolerance information does not exist for all the species living in the Huntington Beach area, the salinity tolerance data presented for several bottom dwelling species (e.g., roundworms live in 2x seawater, isopods tolerate 55^{o}/oo, mysids 43^{o}/oo, hermit crab larvae up to 45^{o}/oo) all suggest that a salinity of 38^{o}/oo would be easily tolerated by the benthic organisms now living around the HBGS. That salinities as high as 38^{o}/oo may have ecological relevance is inferred from EPA guidelines for minimizing salinity effects on the marine biota; EPA suggests a salinity change of not more than 4^{o}/oo take place. Applied to the Huntington Beach discharge this would define an upper value of 33.5^{o}/oo + 4.0^{o}/oo = 37.5^{o}/oo. If 38^{o}/oo is assumed to be a salinity above which benthic organisms are adversely affected, then the models show that this salinity region would extend out to 100 m at 127 mgd flow (i.e., about 7 acres) but would occur only in the immediate vicinity of the vertical discharge at 253 mgd.

One likely biological result of this permanently elevated benthic salinity zone (where bottom salinity drops from 48 to 38°/oo within 100 m) would be some reduction in the total diversity of species living within the zone and the likely increase in the concentration there of species having a greater tolerance to the elevated salinity. Such species may exist already in the Huntington Beach bottom community or species from other nearby coastal habitats (tide pools, bays) where salinity is more variable may be recruited to this zone.

The modeling shows that the presence of a permanent salinity zone of 38°/oo or greater is an inverse function of HBGS cooling-water flow rate; the zone will be larger when HBGS flow rate is smaller (i.e., 127 mgd vs. 253 mgd). The 20-year (1980-2000) HBGS operation record showed that both 127 and 253 mgd were valid descriptors of cooling-water flow. However, since HBGS renovations were completed in 2002, the average flow rate (from 2002 to July 2003) was 265 mgd. Because the area of the permanent zone of salinity elevation to or above 38°/oo is largest a 127 mgd (in-pipe-dilution-ratio = 0.54) and smaller at 253 mgd (dilution ratio = 3.06), it would be further reduced at 265 mgd (3.3).

Further support for the conclusion of minimum discharge effects comes from experimental work carried out at a small RO demonstration facility operated by the Poseidon Corporation adjacent to the Encina Power Plant in Carlsbad, CA. Experiments done there used the 2x RO concentrate seawater in "salinity tests" to confirm previous assessments showing that standardized salinity bioassays with kelp, a larval invertebrate, and a larval fish indicate no effect of prolonged exposure to 36‰. Additional laboratory studies testing the long-term survival of different species in higher salinities and other bioassays are currently in progress.

Additional evidence supporting the conclusion that there will be no discharge-salinity effect is provided by the results of a field study sponsored by the State of Florida and conducted on the Island of Antigua in the West Indies. The study involved experimental assessment of an RO discharge on corals and other organisms living in a tropical reef lagoon. Observations before and for 6 months following the introduction of the discharge of 1.8 mgd of undiluted (57‰) RO outflow seawater indicated no effect on either the organisms living around the point source or those that came into the area.

Marine Biological Considerations Related to the Reverse Osmosis Desalination Project at the Applied Energy Sources Huntington Beach Generation Station

1.0 Introduction

This report evaluates potential marine biological effects resulting from the proposed operation of the Huntington Beach 50 million gallon per day (mgd) reverse osmosis desalination facility located adjacent to the Applied Energy Sources Huntington Beach Generating Station (HBGS). Source water for the desalination operation will be taken from the existing HBGS condenser cooling seawater circulation system and will be pumped at, high pressure, through salt filtering membranes that work by reverse osmosis (RO). The RO process will form approximately equal volumes of freshwater and doubly concentrated (2x) seawater. The 2x seawater will be returned to the HBGS condenser-cooling circulation outflow at point downstream of the RO intake. There it will blend with the up to 407 mgd HBGS cooling water outflow prior to discharge back into the Pacific Ocean. The average ocean salinity at Huntington Beach and the surrounding waters is 33.5‰ (parts per thousand). Addition of the RO 2x concentrate to the HBGS discharge will slightly increase ocean salinity within a small zone around the discharge. This report analyzes the extent of this salinity increase and determines what if any effect it may have on the marine organisms living there.

1.1 The AES Huntington Beach Generating Station

The HBGS has four generators; Units 1 and 2 are rated at 215 megawatts (MW); Unit 3 and 4 are rated at 225 MW each. Each generating Unit has two condensers that are cooled by a once-through seawater flow system; pumps aligned with each Unit withdraw the cooling water through an intake pipe located about 1,840 ft offshore (from the mean high tide line). After it passes over the condensers, the warmed seawater flows back to the ocean. The discharge is a vertical tower positioned about 1,500 ft offshore (from the mean high tide line), where water depth is about 28 ft (bottom distance below mean sea level). The tower rises about 16 ft over the bottom and its opening is 10-15 ft below the water surface, thus the force of the vertically discharged water causes a surface turbulence boil that enhances mixing with the ambient seawater and dissipates heat.

Cooling-water flow rates depend on which and the number of circulating pumps operating. The two pumps each on Units 1, 2 and 4 are rated at 63.4 mgd (380.4 mgd). The two pumps on Unit 3 are rated at 66.7 mgd (133.4 mgd). Thus, the maximum rated water flow for HBGS is about

514 mgd. However, maximum historical flow rate is 507 mgd. Planning for the RO facility used HBGS flow records for 1980-2000. These indicate a bimodal flow distribution; that is, one flow averaging 126.7 mgd and another averaging 253.4 mgd, each account for about 50% of HBGS' operation level. (For expediency these flows were rounded to 127 and 253 mgd and these flow values will be used throughout this report.) When power is being generated the, average delta T value (i.e., the difference between discharge and receiving water temperature) is kept at about 10°C. When the HBGS is on standby and not producing power, the flow rate is 127 mgd and the delta T value is zero. Annual seawater temperature range is about 12 to 19°C.

1.2 The Reverse Osmosis Desalination Facility

The proposed Huntington Beach RO desalination facility will utilize the HBGS cooling seawater stream; access to this water will be downstream of the condenser units (i.e., after seawater is warmed, but before discharge). The RO operation will take approximately 100 mgd, make 50 mgd of freshwater, and return about 50 mgd of approximately 2x concentrate seawater to the HBGS seawater discharge line at point downstream from the RO intake. Mixing with the outflow water will dilute the RO concentrate during progression along the 1,500 ft pipe leading to the offshore discharge tower.

The extent of RO concentrate dilution will depend on the ratio of the HBGS-water flow to the RO concentrate-outflow volume:

$$\frac{\text{Total HBGS Flow} - \text{RO Water Flow}}{\text{RO Concentrate Water Return}}$$

At a 253 mgd flow rate this ratio would be: [253 mgd (total flow) - 100 mgd (to RO)] / 50 mgd (concentrate return) = 3.06. At 127 mgd, the ratio is (127- 100)/50 = 0.54. At a zero delta T, (i.e., the discharge is "unheated" because the HBGS is in standby mode), the higher concentrated effluent will be denser, it will sink more rapidly and mix less with the receiving water however this scenario occurs less than 1% of the time (Jenkins and Wasyl, 2004).

2.0 Marine Species and Communities Occurring in the Waters at Huntington Beach

a. The region. All of the marine species living near the HBGS commonly occur over geographic ranges extending well beyond the coastal waters of Southern California. They are part of a biologically and climatologically unique region called the Southern California Bight (SCB). Geographically, the SCB is an open embayment extending from Point Conception, CA into Baja California, Mexico and 125 miles offshore (Figure 1) (Carlucci et al., 1986; Jackson, 1986). Biologically, the SCB is a transition-zone species assemblage positioned between two larger and diverse assemblages; one in the cooler waters to the north and the other in the warmer waters to the south. SCB organisms comprise a mix of species, some from the cooler, northern- and some from the warmer, southern-regions.

Physical, biological, and oceanographic factors affect the total SCB biomass and cause year-to-year variation in the number of species occurring within the SCB and in areas such as Huntington Beach. While ocean temperature, current patterns, and upwelling affect nutrient and food supplies, biological variables such as the arrival of planktonic animals to coastal areas, the recruitment of new organisms (addition of young-of-the-year to the population) and habitat availability and quality all influence ecosystem-species composition, diversity, and biomass (Jackson, 1986). The young stages of most marine plants, invertebrates, and fishes living at and near Huntington Beach and throughout the SCB begin life as drifting plankton. Their survival into the next life stage requires that the appropriate

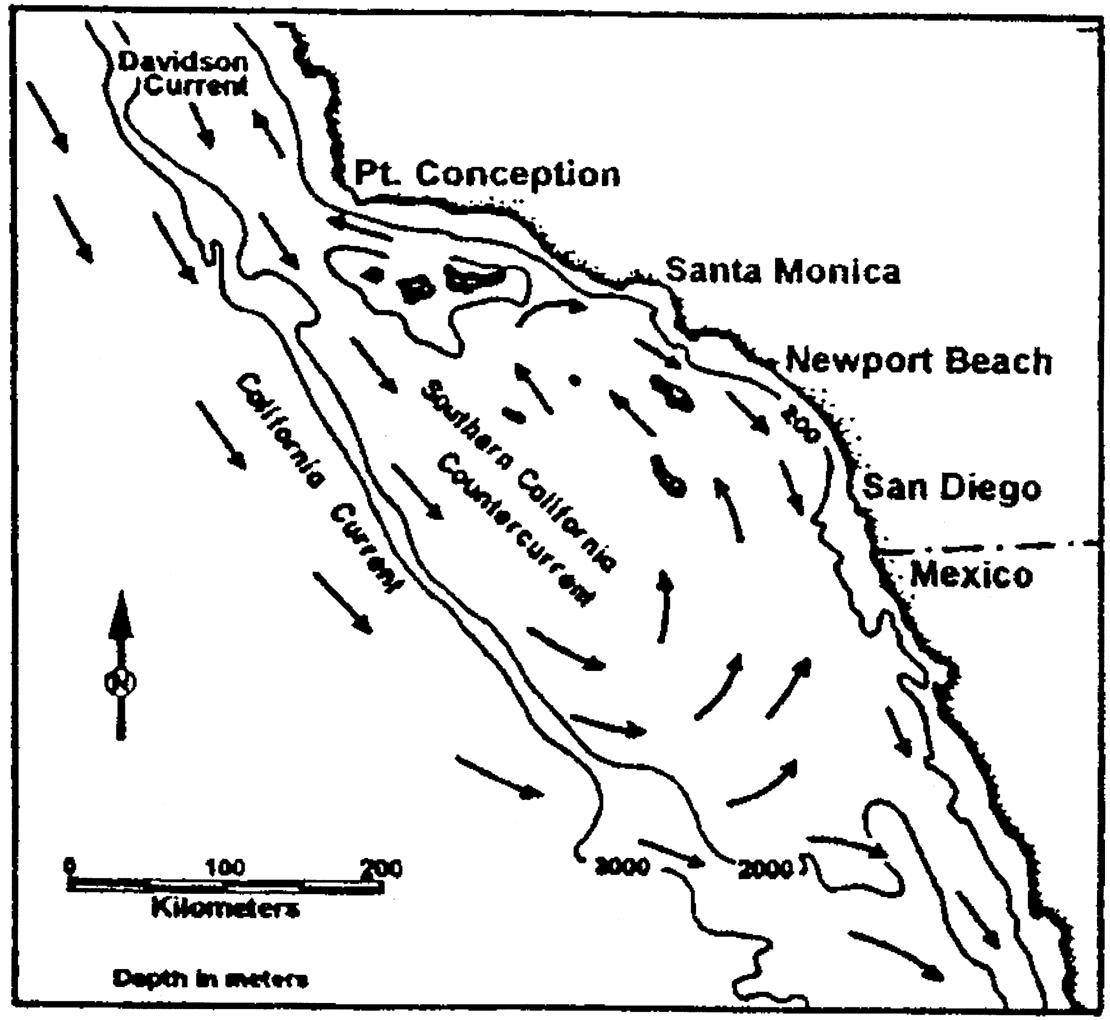


Figure 1. Southern California Bight geography and surface currents.

and vacant habitat be found. Thus, evaluation of either local or regional habitats with respect to their biodiversity, the abundances of different species, and the ages, body size, and growth rates of specific organisms must always be made in the context of the large-scale factors influencing these, whether in the area around Huntington Beach or across the entire SCB.

It is also important to note that the life history characteristics of the species living in the area, most of which are pelagic spawners, are such that fecundity (i.e., egg production) is generally quite high. Most common coastal fish species encountered in MBC surveys exhibit batch spawning, wherein females spawn multiple times (usually ~ once per week) over a spawning season of several months. An average sized female queenfish (*Seriphus politus*) produces approximately 300,000 eggs per season (DeMartini and Fountain, 1981), while average-sized white croaker (*Genyonemus lineatus*) produce approximately 400,000 eggs per season (Love et al., 1984). Smaller coastal spawners also have relatively high fecundity; northern anchovy (*Engraulis mordax*) produce ~500 eggs/batch/gram of female body weight (Hunter and Goldberg, 1980). The same general rule of high fecundity applies for pelagic spawning invertebrates (e.g, Cameron and Rumrill, 1982). For example, females of the California spiny lobster (*Panulirus interruptus*) produce on average

265,000 eggs per spawning season (Tapia-Vasquez and Castro-González, 2000).

Despite the large quantities of eggs produced, egg and larval mortality can be as high as 67% d^{-1} (Fossum, 1998), and therefore very few larvae survive to adulthood or reproductive maturity (Ware, 1975; Underwood and Keough, 2001). The high fecundity of pelagic spawners, therefore, is a necessary compensatory mechanism to maintain the adult population at a steady level. Although it is difficult to obtain realistic estimates of natural mortality, it is clear that high mortality among the early life history stages of most coastal species is 'built into the system', and therefore the effects of larval impingement on overall population levels are likely to be minimal.

b. Organisms and the habitat. Since 1975 National Pollutant Discharge Elimination System (NPDES) requirements for HBGS receiving water monitoring have been carried out by Marine Biological Consultants (MBC) Applied Environmental Sciences (Costa Mesa, CA). Annual reports by MBC (a complete list of these is contained in the bibliography of Jenkins and Wasyl, 2004) have monitored the abundance, diversity, and health status of marine organisms inhabiting the waters and substrata surrounding the HBGS. In addition to recording the environmental conditions and censusing the organisms living near the HBGS heated discharge, MBC sampling has been done at locations 3,000 ft north and south of the discharge. The sampling methods have included diver surveys along bottom transects, trawling for the census of fishes and macroinvertebrates, and bottom-core samples to assess the number and diversity of animals living within the substrate.

Over the years, as monitoring results consistently indicated the absence of discharge effects, the number of surveys required by NPDES was reduced. The MBC report for 1993 contains the most recent (last) analysis of the benthic infauna (i.e., organisms living in the substrate). The 2001 report has the most recent (last) findings of the trawling and diving surveys of benthic marcroinvertebrates.

The sea floor (benthic habitat) surrounding the HBGS discharge is relatively smooth and gently sloping, and contains medium to fine-grain sands. It extends for a considerable distance, both up and down the coast from the discharge site. Littoral currents sweep the waters overlying the coastal sea floor in a generally downcoast direction, although net movement is affected by tides, winds, and storms. These factors and sand grain size play a major role in determining the distribution, abundance, and diversity of benthic animals.

The marine organisms living in the vicinity of the discharge occur in one of three habitat classifications: in the substrate (termed infauna), on the bottom [e.g., macroinvertebrates (worms, crabs, sand dollars, starfish and some fishes)], or in the water column itself (squid, fish, plankton, etc.).

1. Infauna. Huntington Beach infauna surveys were carried out from 1975 to 1993 (MBC, 1993). This habitat is dynamic and there are many species that can potentially occur in the infauna, however, many of these are rare or appear episodically. Most of these animals have very short lives and it is reasonable to assume that many of them arrive each year in the plankton. Thus, the infaunal species diversity of the extended habitat varies from year to year as does organism age, size, and abundance.

Table 1 summarizes the total diversity of infaunal organisms found during the 1993 survey. Table 2 lists the major components of the surveyed infaunal species in order of mean abundance from 1975 to 1993. Figure 2 shows the numbers of species and numbers of individuals found in samples over time. Average animal density was about 43 per liter, but this varied from year to year and by a factor of 5 over 18 years. In terms of both numbers and species, the most dominant animals each year were polychaete worms and crustaceans. Mollusks were the third most abundant group and showed marked variation from year to year. The species comprising the

Table 1. Infaunal species sampled at Huntington Beach, 1993.

Taxon	Species
CNIDARIA	
Anthozoa	
	Renilla kollikeri [1]
NEMERTEA	
	Carinoma mutabilis
	Lineidae, unid.
	Nemertea, unid.
	Paranemertes californica [2]
	Tubulanus cingulatus
	Tubulanus nothus
	Tubulanus pellucidus/polymorphus [3]
SIPUNCULA	
	Siphonosoma ingens
	Thysanocardia nigra
ANNELIDA	
Polychaeta	
	Ancistrosyllis groenlandica
	Acmira catherinae
	Amaeana occidentalis
	Ampharete labrops
	Apoprionospio pygmaea
	Asychis disparidentata
	Chaetozone cf. setosa
	Chaetozone corona
	Chone albocincta
	Chone mollis
	Diopatra ornata
	Diopatra splendidissima
	Glycera convoluta
	Goniada littorea
	*Harmothoe sp. B of SCAMIT**
	Lumbrineris californiensis
	Lumbrineris tetraura
	Lumbrineris spp.
	Magelona pitelkai
	Mediomastus spp. [4]
	Microphthalmus hystrix
	Nephtys caecoides
	Onuphidae unid.
	Onuphis eremita
	Onuphis eremita parva
	Owenia collaris
	Paraprionospio pinnata
	Pectinaria californiensis
	Pista nr. disjuncta
	Podarkeopsis glabrus [5]
	Prionospio lighti [6]
	Scoloplos armiger
	Sigalion spinosa
	Spiophanes bombyx
	Spiophanes missionensis
	Sthenelais verruculosa
	Tharyx sp. A of SCAMIT [7]
	Tharyx tesselata [7]
	Typosyllis aciculata
CRUSTACEA	
Copepoda	
	Paralteutha simile
Ostracoda	
	Euphilomedes carcharodonta
	Euphilomedes longiseta
	Parasterope barnesi
	Rutiderma rostrata
Cumacea	
	Campylaspis sp. C of MBC
	Cumella sp. A of MBC
	Diastylopsis tenuis
	Leptocuma forsmani
CRUSTACEA (cont).	
Isopoda	
	Edotea sublittoralis
	Uromunna ubiquita [8]
Amphipoda	
	Ampelisca brachycladus
	Aora sp. [9]
	Aoridae, unid.
	Argissa hamatipes
	Cerapus " tubularis"
	Ericthonius brasiliensis
	Gibberosus myersi [10]
	Monoculodes hartmanae
	Pachynus barnardi
	Photis californica
	Photis macinerneyi
	Rhepoxynius menziesi [11]
	Rhepoxynius sp. A of SCAMIT [12]
	Stenothoe sp.
	Synchelidium shoemakeri
Decapoda	
	Neotrypaea californiensis [13]
	Ogyrides sp. A of Roney
	Pinnixa forficulimanus
	Pyromaia tuberculata
MOLLUSCA	
Gastropoda	
	Armina californica
	Balcis rutila
	Crepidula norrisiarum
	Crepidula sp.
	Cylichnella harpa
	Kurtziella plumbea
	Nassarius sp.
	Odostomia sp.
	Olivella baetica
	Ophiodermella cancellata
	Philine bakeri
	Rictaxis punctocaelatus
	Sulcoretusa xystrum
	Turbonilla pedroana
Pelecypoda	
	Cooperella subdiaphana
	Macoma sp.
	Mysella sp. A of SCAMIT
	Nucula tenuis
	Periploma planiusculum
	Siliqua lucida
	Solen sicarius
	Tellina modesta
	Yoldia cooperi
PHORONIDA	
	Phoronida, unid.
BRACHIOPODA	
	Glottidia albida
ECHINODERMATA	
Ophiuroidea	
	Amphiodia psara
	Amphiura arcystata [14]
	Amphiuridae sp. A of MBC [15]
	Ophiuroidea, unid.
HEMICHORDATA	
	Enteropneusta, unid. [16]

Source: MBC, 1993

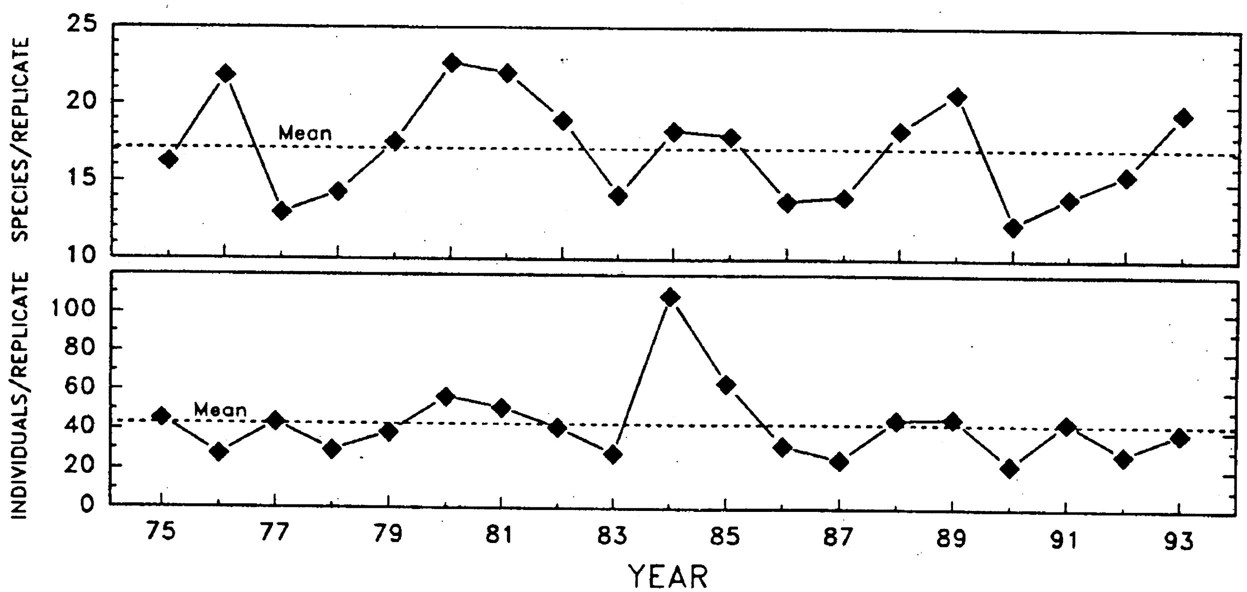


Figure 2. Interannual variation in Huntington Beach infaunal abundance and species richness (averaged for all stations; MBC, 1993).

Huntington Beach benthic infauna are the same as those occurring in other habitats located throughout the SCB. Also, the small-scale and short-term changes in infaunal species assemblages that have been recorded by MBC over several years are typical of such habitats. MBC (1993) concluded that there was no indication that operation of the HBGS had affected the infaunal community, nor was there any indication that any particular infaunal group was more abundant or more frequently found in the discharge area than during the previous 18 years of sampling.

2. Benthic macrofauna. Macrofaunal diver transect surveys, conducted from 1975 to 2000, show the repeated occurrence of the same core group of species in the area (MBC, 2001). The macrofaunal species occurring at Huntington Beach are typical of those expected to occur at other comparable open, sandy bottom habitats throughout the SCB. Graphs showing animal abundance and species number for the area reflect the range of annual differences that commonly occur in shallow water habitats (Figure 3). Average abundances of these and other organisms and total species number varied from year to year. In 1975 and 1980 only 21 species were recorded. In 1994 just after the 1992-1993 El Niño, there were 54 species (Figure 3). Animal densities also varied considerably, from less than $20/m^2$ in 1975 and 1976 to over $160/m^2$ in 1990.

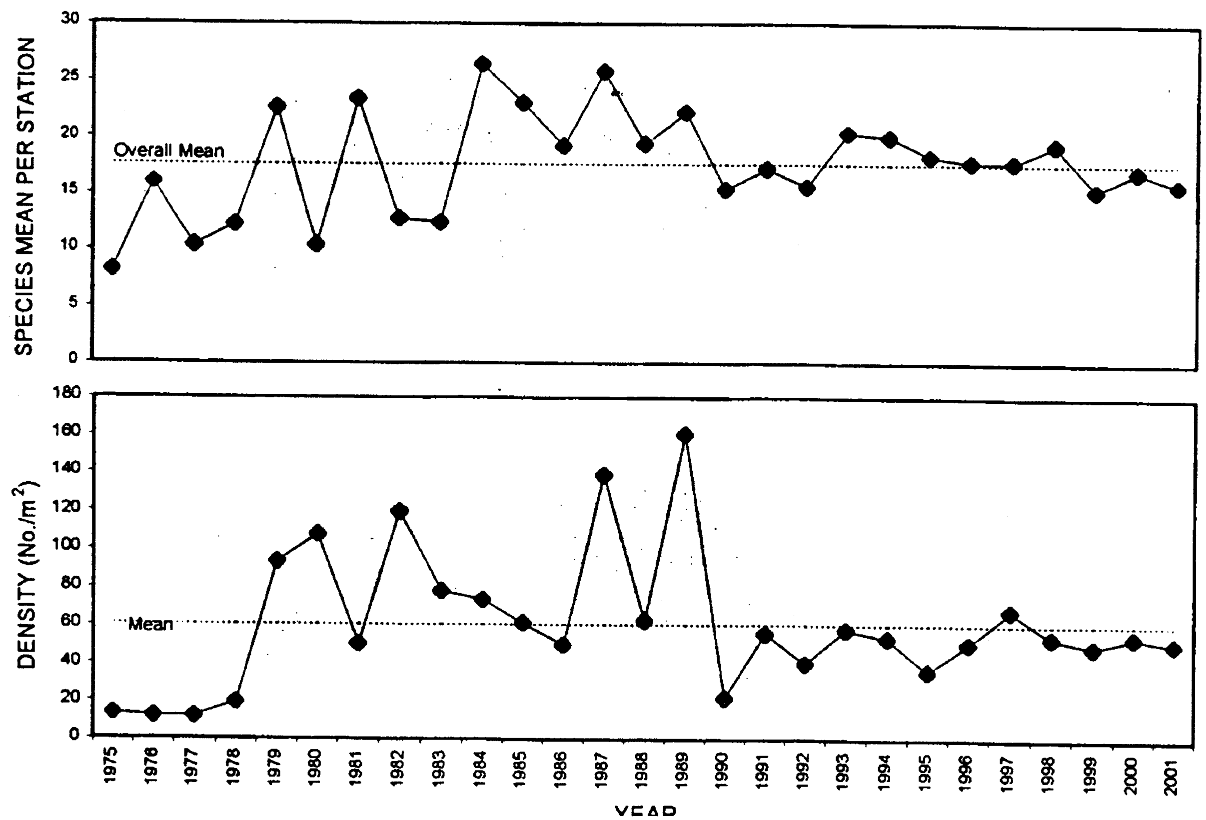


Figure 3. Interannual variation in Huntington Beach macrofauna abundances and species richness, 1975-2001 (MBC, 2001).

Table 2. Order of abundance of key groups of infaunal species at Huntington Beach, 1975-1993.

Species	Year 1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	19-year Mean	S.D.
Apoprionospio pygmaea	680	430	360	360	44	100	300	50	720	440	21	167	42	133	96	88	1513	29	79	297.4	378.5
Rhepoxynius menziesi	–	–	28	150	290	280	150	180	160	340	675	194	212	975	229	413	496	142	73	262.4	250.8
Diastylopsis tenuis	380	120	270	180	540	530	330	160	160	50	25	794	183	438	83	125	54	96	94	242.8	213.7
Goniada littorea	450	370	380	350	290	240	380	220	210	90	192	389	175	171	213	204	13	233	25	241.8	117.8
Olivella baetica	130	90	44	140	110	25	110	110	4	60	1950	11	29	33	21	33	25	8	1	154.4	460.3
Owenia collaris	–	–	–	180	240	180	800	–	150	40	88	–	–	8	750	54	400	–	4	152.3	258.5
Polydora nuchalis	–	–	–	–	–	–	340	–	30	1470	167	72	–	–	–	–	–	–	–	109.4	358.5
Crepidula naticarum	–	–	–	20	–	20	70	50	–	1670	104	28	–	25	–	–	–	–	–	104.6	401.3
Chaetozone cf. setosa	60	120	210	20	17	60	10	250	40	20	292	11	200	13	183	121	42	92	14	93.4	94.4
Tharyx sp.	690	280	170	30	17	30	70	80	40	40	–	161	38	–	–	–	–	–	38	88.5	171.9
Mediomastus spp.	–	–	–	100	250	230	80	80	10	30	13	122	233	38	42	100	4	250	48	85.8	85.7
Leitoscoloplos pugettensi	40	210	180	50	39	150	80	300	80	40	92	122	71	–	13	–	4	83	–	81.8	83.9
Tellina modesta	10	–	10	50	90	680	110	50	10	120	8	28	79	17	29	8	–	–	10	68.9	160.3
Dendraster excentricus	–	120	–	–	6	–	130	150	20	310	21	6	12	46	117	21	63	142	–	61.2	82.8
Eohaustorius washingtonianus		–	–	190	90	4	10	13	–	90	50	56	100	108	200	83	50	50	–	60.8	63.7
Prionospio lighti*	70	50	40	50	17	200	4	70	30	30	21	6	–	271	58	79	8	63	5	56.5	71.9
Amaeana occidentalis	5	50	50	40	56	10	60	20	10	180	104	–	33	13	4	4	–	258	96	52.3	48.4
Pectinaria californiensis*	40	20	20	70	17	20	10	40	20	320	88	–	8	179	21	8	13	–	4	47.2	81.4
Spiophanes bombyx	50	20	20	30	22	50	20	–	90	170	100	17	21	71	63	33	33	58	24	47.0	41.7
Magelona sacculata	–	–	–	30	33	190	30	80	10	10	150	–	12	46	67	63	75	33	–	43.6	54.3
Pholis spp.	60	–	20	–	–	10	17	30	–	410	46	44	4	25	4	4	25	–	–	36.8	96.8
Paraprionospio pinnata	–	40	10	–	6	20	140	100	20	180	17	61	33	8	4	–	–	46	8	36.5	53.4
Ampharete labrops	–	–	10	10	16	30	4	10	10	440	42	22	–	4	38	8	25	8	4	35.8	104.1
Amastigos acutus	–	–	–	–	250	260	80	4	50	–	4	–	–	–	–	–	–	–	–	34.1	84.5
Typosyllis spp.	120	170	–	80	–	–	30	30	40	–	–	–	42	33	29	38	13	–	–	32.9	47.1
Leptocuma forsmanni	20	10	20	20	60	30	20	–	4	11	8	33	29	88	121	42	33	63	10	32.7	31.4
Isocheles pilosus	–	4	10	–	–	330	–	20	10	–	–	6	–	100	96	–	8	–	–	30.7	82.4
Leptopecten latiauratus	5	–	40	–	–	30	40	20	10	290	29	6	–	–	–	–	–	–	–	24.7	69.2
Thalenessa spinosa***	20	50	30	4	17	20	21	20	20	110	59	–	17	8	–	17	–	–	–	21.7	27.3
Rhepoxynius spp.	5	10	10	120	–	20	10	–	–	–	50	17	29	55	–	4	17	8	–	18.7	30.8
Neverita recluziana	–	–	–	–	6	4	10	20	10	130	42	6	8	13	8	–	–	–	–	13.5	31.4

* previously Prionospio cirrifera
** previously Cistena californiensis
*** previously Eusigalion spinosum
Source: MBC 1975–1992

Table 3. Yearly and mean survey-wide community parameters for key macrofaunal species, 1975-2001.

	Year																												Percent
	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Mean	Total
Total Number of Species	21	38	23	27	48	21	39	24	25	54	43	36	43	32	46	29	37	32	40	29	26	29	26	31	24	27	25	32.4	
Mean Number of Individuals (per m²)	13.6	11.8	11.8	19.3	93.3	107.3	50.2	119.4	78.0	73.7	61.8	49.9	139.1	63.1	160.7	22.0	56.1	40.5	58.1	53.6	36.2	51.0	66.4	53.9	49.4	54.5	51.3	61.0	
Mean Densities of Key Species (per m²)																													
Diopatra spp	10.2	5.1	7.7	10.2	10.9	17.8	19.1	23.2	28.6	28.1	43.9	39.1	26.2	10.2	7.9	11.1	40.0	19.6	42.4	43.8	29.0	40.0	23.3	45.5	42.1	44.7	38.2	26.2	45.1
Paguridea, unid. (includes *Isocheles* sp)	0.0	1.8	1.1	0.2	2.0	0.2	1.6	90.4	0.7	0.5	3.7	0.7	101.9	13.6	128.3	0.5	0.3	10.7	0.3	0.4	0.1	0.5	0.4	0.1	0.2	0.1	0.7	13.4	23.0
Owenia spp	-	-	-	2.1	67.5	85.9	16.2	-	6.6	1.8	0.1	-	0.0	1.8	1.1	0.6	7.4	0.0	0.0	0.1	0.0	0.0	-	0.2	-	-	-	7.1	12.2
Dendraster excentricus	-	-	-	-	-	-	-	-	35.0	20.2	0.0	-	-	2.5	11.8	1.1	0.4	-	-	-	-	-	36.9	-	-	-	-	4.0	6.9
Maldanidae, unid.	0.1	0.2	1.3	1.2	2.7	0.0	1.0	0.3	0.3	0.6	2.3	0.2	1.1	1.0	3.0	2.8	3.1	7.1	3.6	0.2	0.8	1.2	1.7	0.6	0.5	0.8	1.6	1.5	2.5
Ophiuroidea, unid.	-	0.1	0.0	0.0	0.1	-	0.2	0.0	0.3	1.2	2.1	0.7	1.9	0.4	0.6	2.9	1.5	0.4	3.7	1.2	1.5	1.4	1.4	2.6	1.6	3.3	1.0	1.1	1.9
Leptopecten latiauratus	-	-	-	-	0.1	-	0.1	-	-	0.3	1.5	-	0.0	14.0	0.0	-	0.0	0.1	0.0	0.9	0.1	0.1	0.0	0.0	0.0	0.2	0.2	0.7	1.1
Balanus spp	0.0	0.3	-	-	0.3	0.4	2.6	2.1	-	0.0	0.1	0.2	0.3	-	2.3	0.1	0.1	0.3	1.7	0.9	0.4	2.1	0.1	-	0.1	1.8	1.5	0.7	1.1
Crepidula spp	-	0.1	-	-	-	-	0.1	1.7	0.1	0.6	0.7	0.7	0.5	0.9	0.9	0.9	0.3	0.3	0.5	1.9	-	-	0.0	0.5	0.1	0.1	1.8	0.5	0.8
Majidae, unid.	-	-	-	-	-	-	-	-	-	-	-	-	0.1	0.1	0.0	0.1	0.0	0.1	0.7	1.5	0.1	2.5	0.5	0.5	0.7	0.8	4.5	0.5	0.8
Zaolutus actius	-	0.0	0.0	-	0.4	0.0	1.0	0.0	0.6	0.6	0.0	0.2	0.1	-	-	-	0.0	0.1	0.9	0.2	0.7	0.5	0.2	0.8	2.2	0.5	0.2	0.3	0.6
Olivella spp	1.9	0.2	-	0.0	0.2	-	0.1	0.0	-	0.7	0.4	0.0	0.1	2.2	0.3	0.1	0.0	-	0.0	0.3	-	0.0	0.1	0.2	-	0.1	0.1	0.3	0.4
Spiochaetopterus costarum	0.1	0.1	0.0	0.1	0.2	-	0.1	0.2	0.1	0.1	0.1	0.7	0.1	0.6	-	0.5	1.0	0.7	0.1	0.0	0.1	0.0	0.9	0.5	-	-	-	0.2	0.4
Astropecten armatus	0.0	0.1	0.1	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.3	0.9	0.3	0.4	0.5	0.4	0.6	0.1	0.1	0.2	0.2	0.4	0.2	0.3
Dendronotus frondosus	-	-	-	-	4.0	-	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1	0.3
Nassarius spp	-	0.0	-	0.0	0.1	0.0	0.1	-	-	0.6	0.1	0.1	0.3	1.6	0.1	0.1	0.1	0.0	0.1	-	-	0.0	0.2	0.0	0.2	0.1	0.1	0.1	0.3
Pista spp	-	0.1	0.1	0.0	0.1	0.1	0.2	-	0.2	-	0.6	0.1	1.2	-	-	0.2	0.3	0.2	0.1	0.1	-	-	-	0.0	-	0.0	0.0	0.1	0.2
Hiatella arctica	-	-	-	-	-	-	-	-	3.3	0.2	-	0.0	-	-	0.0	-	-	-	-	0.0	-	-	-	-	-	-	-	0.1	0.2
Phyllochaetopterus spp	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.4	-	-	0.0	-	-	1.3	0.8	0.6	-	-	-	-	0.1	0.2
Stylatula elongata	0.0	0.0	-	-	-	-	0.0	-	0.0	0.2	0.2	-	0.0	-	-	-	-	0.1	0.6	0.4	0.3	0.1	0.4	0.3	0.1	0.2	0.2	0.1	0.2
Renilla kollikeri	-	-	-	-	0.0	-	0.0	0.0	-	0.0	0.1	0.1	0.3	0.2	0.2	0.2	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.2
Solen spp	-	-	-	-	-	-	-	-	-	1.1	0.0	-	-	-	-	-	-	-	1.2	0.3	0.2	0.0	-	-	-	-	-	0.1	0.2
Pyromaia tuberculata	0.0	0.0	-	-	0.2	-	0.7	0.0	0.0	0.4	0.2	0.0	0.0	-	0.0	0.0	0.0	0.0	-	-	-	0.1	0.3	0.2	0.4	0.0	-	0.1	0.2
Chaetopterus variopedatus Cmplx	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.6	0.1	0.0	0.1	0.1	0.3	0.2	0.1	0.2	0.2	0.4	0.1	0.1	0.1	0.2
Harenactis attenuata	0.1	-	-	-	-	-	-	-	-	-	-	-	0.1	0.0	0.1	0.3	0.2	-	-	-	-	-	-	0.4	0.35	0.8	-	0.1	0.1
Polygireulima rutila (Balcis rutila)	-	0.0	0.0	-	0.0	-	0.1	0.0	0.0	0.3	-	0.5	0.4	0.5	0.1	-	-	-	-	-	-	-	-	0.1	0.02	-	-	0.1	0.1
Thalamorporella spp	-	0.1	0.1	-	0.2	-	0.2	0.4	-	0.1	0.1	0.1	-	-	0.0	0.1	0.0	-	0.2	-	-	-	-	-	-	-	-	0.1	0.1
Neverita reclusiana	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	-	0.0	0.1	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Ophiodermella spp	-	-	0.0	0.0	-	0.1	0.3	0.0	-	0.1	0.0	-	0.0	-	-	0.0	0.0	0.1	0.1	-	-	0.0	0.0	0.1	0.2	0.2	0.1	0.1	0.1
Anthozoa, unid.	-	-	-	-	-	0.1	-	-	-	0.4	0.4	-	-	-	-	-	-	-	-	-	-	-	-	0.3	0.1	-	-	0.0	0.1
Argopecten circularis	-	-	-	-	-	-	-	-	-	-	0.3	0.0	0.1	-	-	-	-	0.0	0.7	-	-	-	-	-	-	-	-	0.0	0.1

For 1975 and 1978 data was taken from the same 5 stations sampled since 1977
Note: 0.0 = <0.05

Source: MBC, 2001

Table 3 lists key macrofaunal invertebrate species surveyed at Huntington Beach from 1975 to 2001. During these years, five animal groups [three annelid (polychaete) worms (*Diopatra*, *Owenia*, Maldanidae), hermit crabs (Paguridae) and Pacific sand dollars (*Dendraster excentricus*)] account for about 90% of the macrofaunal abundance. The relative numbers of these organisms vary from year to year and in different localities and they could be especially abundant, with as many as 3,600-9,000 individuals of various species (sand dollars, polychaete worms, hermit crabs) being taken in one otter trawl net at one sampling site. Pacific sand dollars, for example, were found in great abundance near the discharge and at the upcoast sampling area in 1997, but had not been found in these areas in the preceding four years and have appeared variably at all stations over the survey and are not consistently found in the waters around the HBGS.

Macroinvertebrates are also frequently taken in otter trawl samples. These species censuses are typically done during diver transect surveys as well, but are prone to otter trawl collection due to their size or relative position in the water column. The dominant macroinvertebrate species collected by otter trawl in recent years are spiny sand stars (*Astropecten armatus*), penicillate jellyfish (*Polyorchis penicillatus*), tuberculate pear crab (*Pyromaia tuberculata*), and blackspotted bay shrimp (*Crangon* *nigromaculata*) (MBC, 2001). Similar to the trends observed during diver surveys, otter trawl data reflect variability in the invertebrate community that is likely attributable to the patchy distribution of these species.

3. Fishes. Since the fish surveys began, 65 species have been collected, all of which can be considered as typical residents of open sandy bottom coastal habitats in southern California (Horn and Allen, 1978; Mearns, 1979; Allen and DeMartini, 1983). The numbers of fish species taken in Huntington Beach trawl surveys ranged from 13 in 1999 to 29 in 1986 and averaged 22 species/year. The fifteen most abundant fish species living in the area between 1976 and 2000 were: white croaker, queenfish, northern anchovy, California halibut, Pacific sardine, speckled sanddab, curflin turbot, kelp pipefish, white seaperch, walleye surfperch, C-O turbot, Pacific butterfish, California lizard fish, salema, and barred surfperch. Table 4 lists yearly abundance of all demersal species taken by otter trawl from 1976 to 2001. The persistent representation of the same species indicates that the fish fauna is relatively stable.

Table 4. Yearly abundance of demersal fish species taken by otter trawl, 1976-2001.

	Year																											Percent
	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Total	Total
Engraulis mordax	356	3126	2460	6253	186	3138	1	8401	1145	5	61	40	386	11	####	381	3916	####	507	221	826	35	1409	-	628	9	72823	50.205
Genyonemus lineatus	1773	3743	7503	2405	3407	1324	309	1777	1021	890	1200	1017	663	28	239	75	3878	4555	913	780	24	473	103	1	118	390	38609	26.618
Seriphus politus	1822	134	1119	297	1712	2580	529	3968	3058	677	695	303	116	1	602	64	3883	2595	579	654	91	430	199	-	495	125	26728	18.427
Phanerodon furcatus	59	275	148	406	22	378	13	63	4	18	10	4	1	-	1	2	-	9	6	5	-	1	1	-	-	-	1426	0.983
Hyperprosopon argentum	145	254	148	75	76	-	-	33	-	-	-	-	11	-	-	-	1	3	-	-	-	12	1	-	2	20	781	0.538
Paralichthys californicus	7	80	51	12	25	35	72	22	24	40	31	39	52	28	19	25	41	17	11	6	4	13	5	7	1	11	678	0.467
Amphistichus argenteus	18	206	34	167	26	32	-	2	-	1	-	-	-	1	1	-	-	8	-	2	4	1	-	-	6	8	517	0.356
Citharichthys stigmaeus	14	85	5	2	6	-	17	-	-	51	6	67	43	25	40	14	5	8	20	5	21	3	9	18	22	11	497	0.343
Peprilus simillimus	68	1	41	4	13	2	2	137	105	4	15	-	2	-	23	2	12	-	-	5	1	-	38	-	-	-	475	0.327
Cymatogaster aggregata	7	62	41	160	13	78	7	45	-	1	1	-	-	-	3	-	1	4	6	1	2	-	16	-	4	13	465	0.321
Synodus lucioceps	-	5	27	7	-	10	223	1	3	-	3	3	3	39	11	2	31	-	-	1	-	-	9	29	-	21	428	0.295
Pleuronichthys ritteri	-	2	-	2	1	1	12	1	7	11	7	32	21	25	4	20	6	5	2	-	1	-	-	-	-	1	161	0.111
Xystreurys liolepis	-	3	1	2	3	4	32	6	4	18	3	14	9	6	5	12	5	5	1	4	-	-	1	8	1	3	150	0.103
Sardinops sagax	-	-	-	-	-	-	-	-	2	-	-	-	-	-	67	-	7	-	12	-	8	-	46	-	-	-	142	0.098
Leptocottus armatus	-	8	1	-	1	-	-	2	-	38	4	6	49	4	2	-	5	6	2	-	-	1	-	3	6	2	140	0.097
Menticirrhus undulatus	5	3	9	21	2	2	8	8	3	16	8	2	2	-	2	1	3	4	1	-	1	10	14	1	4	-	130	0.090
Anchoa compressa	-	-	-	-	-	1	1	1	1	-	-	-	4	-	-	1	1	10	-	-	-	30	68	-	-	-	118	0.081
Symphurus atricauda	10	11	15	2	1	1	5	3	6	11	8	13	9	4	-	-	-	6	-	-	-	-	-	-	-	-	105	0.072
Syngnathus spp.	5	39	5	2	1	2	4	1	-	-	6	4	14	1	4	-	5	1	1	-	1	-	2	2	-	-	100	0.069
Pleuronichthys verticalis	5	6	16	2	4	5	11	1	1	19	2	9	-	3	-	-	-	1	-	-	-	-	-	9	-	1	95	0.065
Myliobatis californica	-	-	11	8	1	4	1	10	-	11	1	-	-	-	-	1	1	4	-	6	-	5	2	-	18	-	84	0.058
Ophidion scrippsae	1	1	43	-	-	-	-	1	-	1	22	-	1	-	-	-	-	-	-	-	-	-	1	-	-	-	71	0.049
Platyrhinoidis triseriata	-	9	-	3	1	-	-	2	1	13	3	10	4	6	-	2	-	1	1	-	1	-	2	-	-	-	59	0.041
Hypsopsetta guttulata	-	1	3	2	3	1	6	6	-	-	2	2	-	2	-	2	-	1	1	-	-	1	-	-	-	2	35	0.024
Paralabrax nebulifer	-	-	1	-	-	-	3	3	3	1	4	1	2	2	2	-	-	1	1	2	-	-	1	1	-	-	28	0.019
Cheilotrema saturnum	-	-	-	-	-	2	-	13	1	2	2	1	-	-	-	-	-	1	3	1	-	-	-	-	-	-	26	0.018
Embiotoca jacksoni	6	-	1	-	-	10	-	-	-	1	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	22	0.015
Rhinobatos productus	2	3	2	1	-	-	-	-	1	-	-	-	1	6	-	-	-	-	-	-	-	-	-	1	1	-	18	0.012
Mustelus henlei	1	3	-	-	-	-	-	-	-	1	-	-	1	1	-	1	1	1	-	-	-	5	-	-	1	-	16	0.011
Heterostichus rostratus	-	1	-	-	-	1	-	-	-	2	1	2	1	-	-	-	-	1	2	-	-	-	1	-	-	-	12	0.008
Porichthys myriaster	-	4	-	-	1	-	-	-	-	-	2	-	1	-	-	1	-	-	-	-	-	-	2	1	-	-	12	0.008
Sphyraena argentea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	4	-	-	-	-	1	-	-	-	-	9	0.006
Atherinopsis californiensis	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	2	1	-	-	1	-	1	1	-	-	-	8	0.006
Squalus acanthias	-	-	-	-	-	-	-	-	-	3	-	2	2	-	1	-	-	-	-	-	-	-	-	-	-	-	8	0.006
Atractoscion nobilis	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	2	-	1	-	6	0.004
Chromis punctipinnis	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	2	1	6	0.004
Damalichthys vacca	1	1	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	6	0.004
Girella nigricans	-	1	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	5	0.003
Paralabrax clathratus	-	-	1	-	1	-	-	1	-	-	1	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	5	0.003
Microstomus pacificus	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	0.003
Syngnathus californiensis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	4	0.003
Chilara taylori	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	0.002
Scorpaena guttata	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	3	0.002
Trachurus symmetricus	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	3	0.002
Xenistius californiensis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	3	0.002
Citharichthys xanthostigma	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	2	0.001
Leuresthes tenuis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	2	0.001
Pleuronectes vetulus	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	2	0.001
Porichthys notatus	-	-	1	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	0.001
Sebastes paucispinis	-	1	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	2	0.001

	Year																											Percent
	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Total	Total
Triakis semifasciata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1	-	-	-	-	2	0.001
Anchoa delicatissima	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	1	0.001
Dorosoma petenense	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0.001
Galeorhinus zygopteros	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0.001
Gibbonsia elegans	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1	0.001
Halichoeres semicinctus	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0.001
Heterodontus francisci	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0.001
Hypsoblennius gilberti	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	1	0.001
Pleuronichthys coenosus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1	0.001
Pleuronichthys decurrens	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	0.001
Raja inornata	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0.001
Scomber japonicus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	1	0.001
Sebastes serranoides	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0.001
Semicossyphus pulcher	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0.001
Torpedo californica	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0.001
Number of individuals	4309	8068	11693	9834	5508	7613	1256	14513	5392	1836	2102	1572	1402	194	20638	608	11808	26963	2078	1696	986	1031	1933	82	1314	621	145050	
Number of species	21	28	28	22	24	23	19	28	20	25	29	21	26	19	20	18	21	25	23	17	14	21	23	13	17	17	65	
Number of stations sampled	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	6	6	6	6	6	6	6	6		

Source: MBC, 2001

c. Conclusions of the MBC monitoring. The overall findings of MBC in its NPDES monitoring program are as follows (MBC, 2001):

- Operation of the HBGS had no detectable adverse effects on the marine biota or the beneficial uses of the receiving waters.
- Although the numbers and relative abundance rankings of species shift from year to year, there are strong indications that a relatively stable assemblage of organisms occurs in the marine habitats near the discharge.
- All of the organisms occurring in waters adjacent to the HBGS have much broader geographic distributions, extending in most instances to beyond the range of the Southern California Bight.
- Both the sea floor and littoral water habitats occurring near the HBGS discharge site are not home to any endangered marine species.
- The area does not have any "environmentally sensitive" habitats such as eel grass beds, surf grass, rocky shores, or kelp beds.
- The movement, abundance, and diversity of invertebrate and fish populations along the Huntington Beach coast appear all to be in response to natural ecological factors and not adversely affected by the HBGS discharge.

3.0 Modeling of the Combined Discharge Dispersion.

The HBGS discharge is through a vertical tower located 1,500 ft offshore from the mean high tide line. The force of the discharge is sufficient to broach the water surface and form a boil. From its central core, this boil expands outward and rapidly mixes with the receiving water. Jenkins and Wasyl (2004) applied the US Navy Coastal Water Clarity Model to analyze aspects of the dispersal and dilution of the combined heated (or unheated during HBGS standby) and RO (a 50 mgd 2x seawater return rate is assumed in all cases) discharge. Their objective was to predict how differences in discharge characteristics (salinity/density, temperature, and volume) interact with variations in ocean mixing processes. Maps showing these effects on the discharge plume's salinity and temperature profiles in the nearshore environment enable estimates of the magnitude and duration of marine-organism exposure to above-ambient salinity and temperature. The accuracy of these models and their applicability to these issues has been verified by independent analysis (Grant, 2003) and by findings in general agreement with previous works (CA Coastal Commission, 1993).

The models operated on the bimodal (127 and 253 mgd) flow history for HBGS from 1980-2000 (Jenkins and Wasyl, 2004). Flow rate is the most important factor in modeling the combined discharge dispersal because it determines the "in-pipe dilution ratio." Another important factor is HBGS delta T (10°C) which, together with discharge salinity, determines discharge-water density and thus its mixing potential with the receiving water. Also important are a series of inter-related coastal oceanographic features (e.g., temperature, salinity, water level, tides and tidal currents, wave height) and weather factors (wind speed) that affect ocean vertical mixing and therefore the dispersal and dilution of the discharge by the receiving water. Data on receiving-water mixing potential were also obtained from 20-year (1980-2000) records.

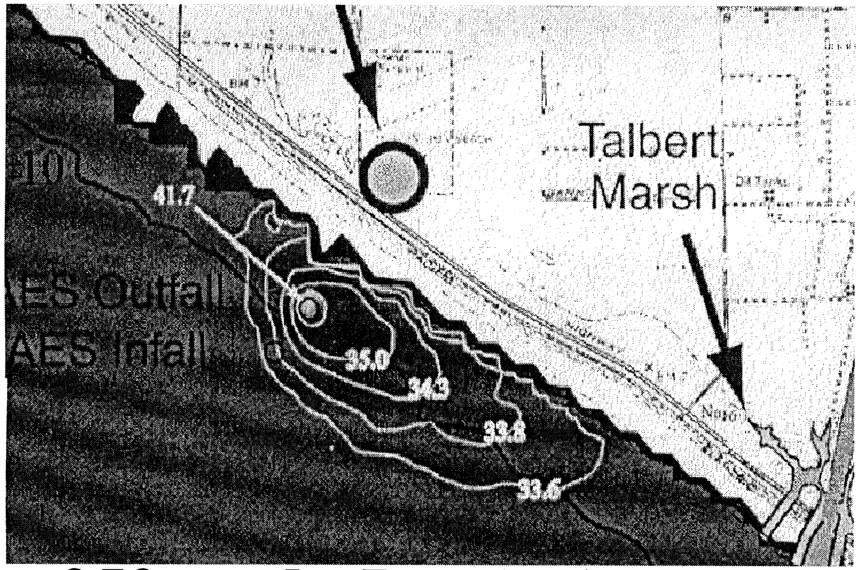
Figure 4 compares bottom and mid-water column integrated salinity distribution maps modeled for a combined discharge of 50 mgd RO concentrate with a heated HBGS discharge (delta T =10°C) at the 127 and 253 mgd flow-rate cases. The common features these two maps are:

- the highest salinity occurs at the discharge site
- the salinity contours move predominantly downcoast
- all seabed salinity contours are expanded relative to those in mid-water

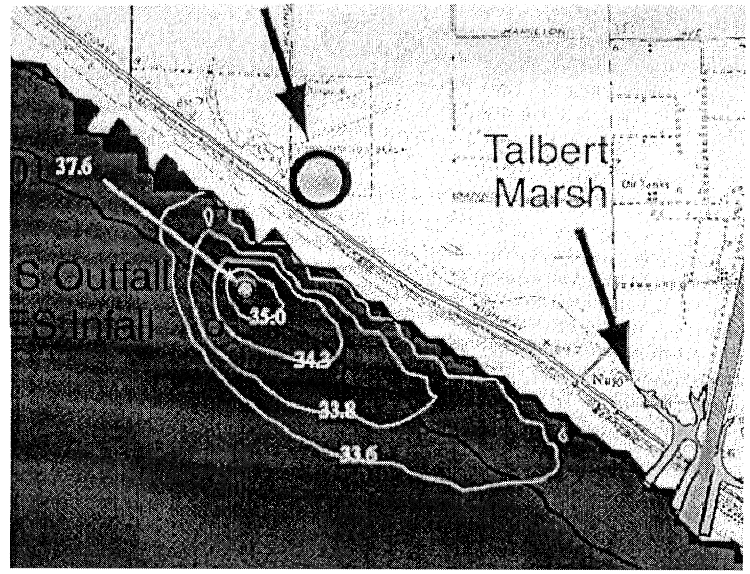
The salinity highs in the discharge core are about 55‰ at 127 mgd and 42‰ at 253 mgd. Because the combined RO and warm discharge water will have a greater density, a "salt wedge" forms as the discharge momentum is dissipated by distance from the core.

The salt wedges associated with the two flow scenarios seen in Figure 4 can be compared for their longshore depth-salinity profiles (Figure 5). Jenkins and Wasyl (2004) designate three salinity regions around the discharge; the inner core, where salinity is greatest, the outer core where it is rapidly declining, and salt wedge; these can all been seen in Figure 5. Long- and cross-shore salinity transects through the discharge tower enable comparison of the relative size of the elevated salinity regions resulting from the two flow scenarios (Figure 6).

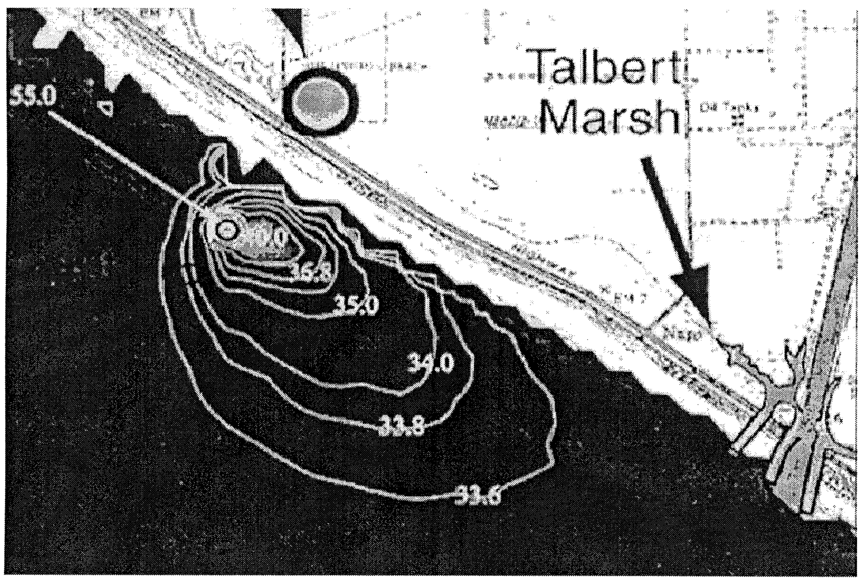
Figures 4 and 5 show that a zone having a variable but elevated salinity will form around the discharge and this would become diluted as flow moves downcoast. Both the area of this zone and its salinity elevation would depend primarily upon HBGS flow rate. While ocean and weather-related factors affecting receiving water dispersal capacity have importance, times when receiving-water conditions would be "sub-optimal" for mixing are rare (i.e., these require simultaneous co-occurrence and persistence of the different ocean mixing factors) and they would not last very long. Also, to have a marked effect on discharge-field salinity, "sub-optimal" receiving water mixing conditions would have to also co-occur with times of low



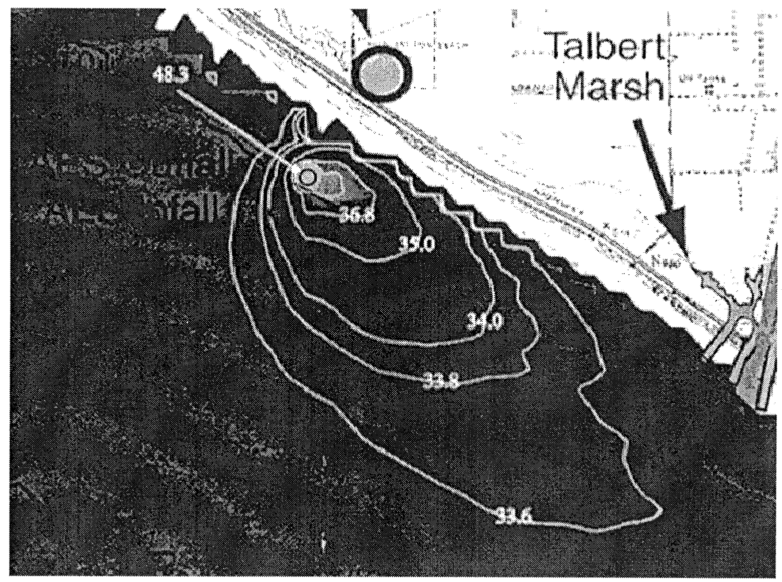
253 mgd - Depth-Averaged



Bottom



127 mgd - Depth-Averaged



Bottom

Figure 4. Depth-averaged and bottom salinity patterns for the 253 mgd and 127 mgd flow scenarios (Jenkins and Wasyl, 2004).

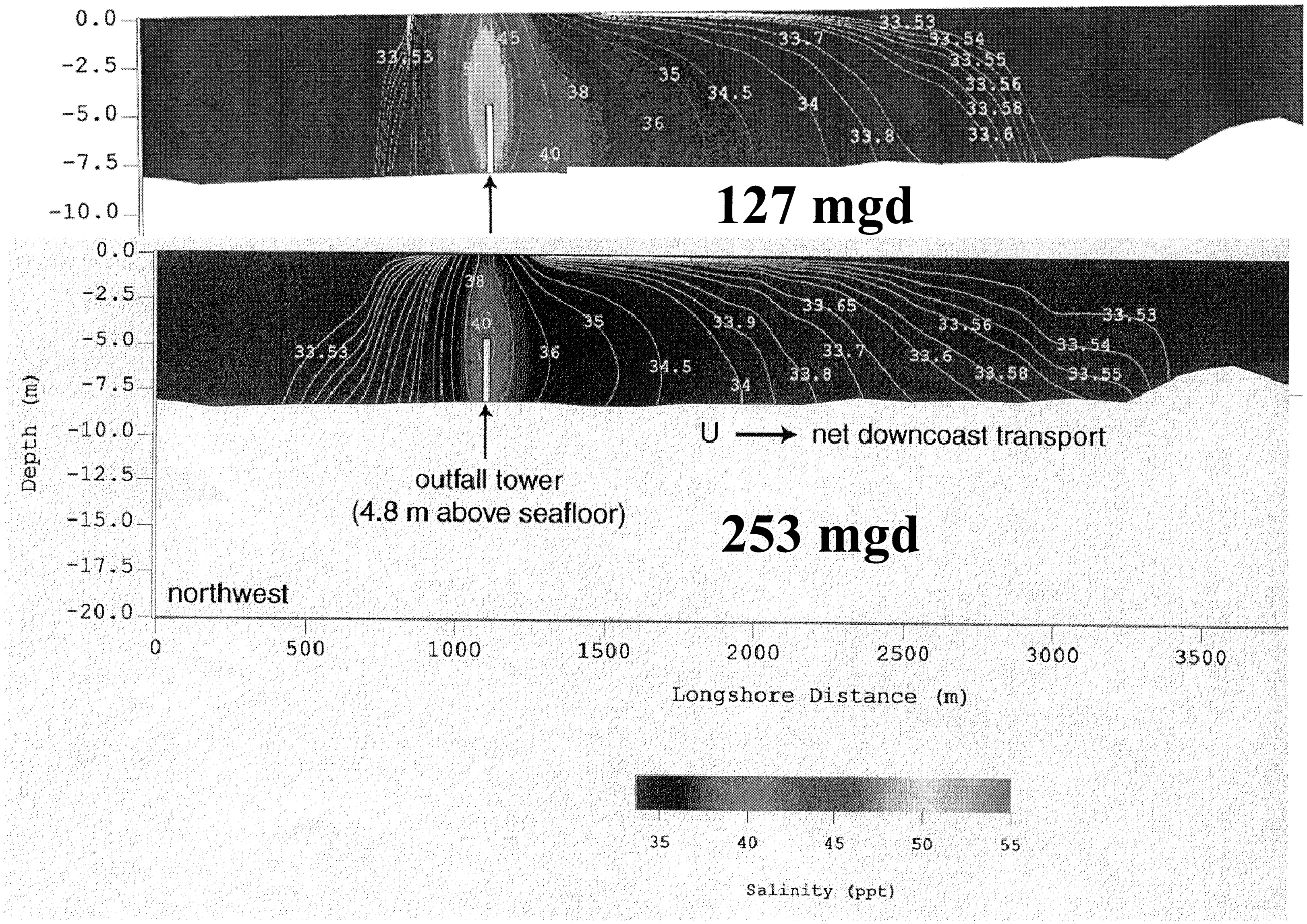


Figure 5. Longshore salinity profiles for the two flow scenarios modeled by Jenkins and Wasyl (2004).

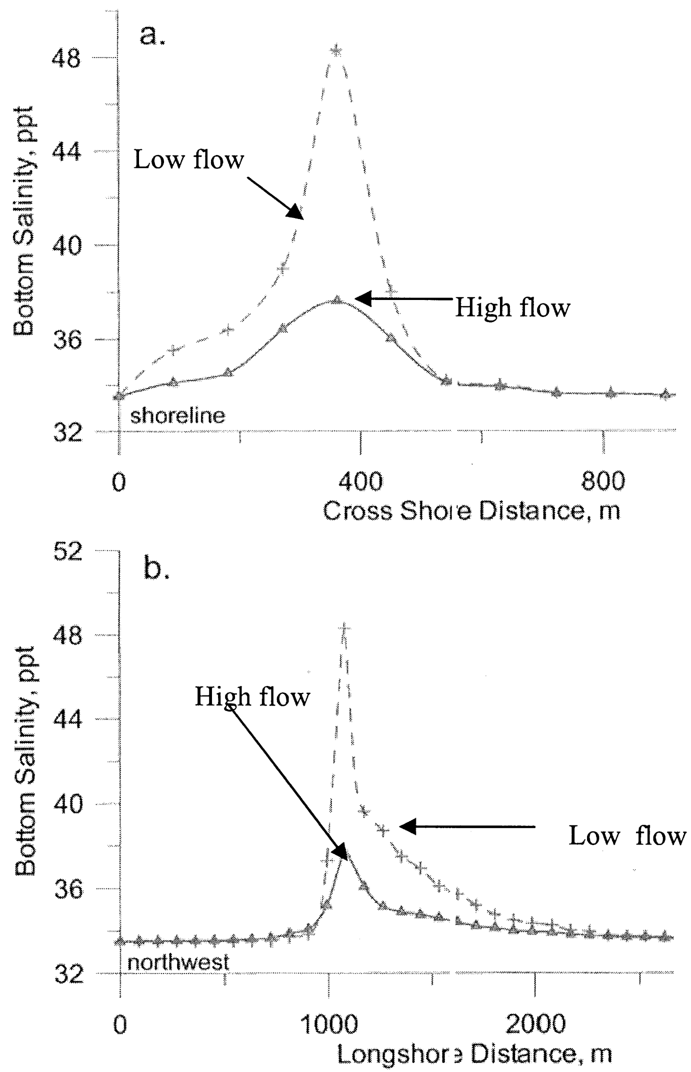


Figure 6. Long- and cross-shore 30 day bottom salinities for the low and high flow scenarios (Jenkins and Wasyl, 2004).

HBGS flow rate (which are also episodic, short in duration, and unlikely to occur during the warmer season, when sub-optimal ocean mixing conditions are more probable).

Table 5 summarizes the fine-scale changes in bottom and depth-averaged salinity determined for the 127 and 253 flow regimes by Jenkins and Wasyl (2004). This shows that, from the core out to 150 m, salinities under the 127 mgd flow regime range from 55 to 39°/oo in the water column and from 48 to 37°/oo on the seabed.

The model incorporating a zero delta T with 127 mgd flow showed only a slight (+1°/oo) salinity elevation over that determined for the heated discharge. For the 253 mgd flow, salinities range from 42 to 35°/oo in the water column and from 39 to 35°/oo on the seabed.

Table 6 compares the estimated relative areas of different selected salinity contours that will form on the seabed and in the water column under the 127 and 253 mgd flows. These areas were calculated with respect to "distances out from the core" and interpolated for specific salinities using

Table 5. Summary Data on Dispersal Salinity (Jenkins and Wasyl, 2004)

Variable	Flow Scenarios	
Flow rate (mgd)	127	253
RO 2x concentrate (mgd)	50	50
Dilution ratio*	(127-100)/50 = 0.54	(253-100)/50 = 3.06
Maximum salinity (^{o}/oo) at Distance (m) from Discharge		
0- mid-depth	55	42
-base of Tower	48	39
50- mid-depth	45	37
- bottom	40	36
100- mid	43	37
- bottom	38	35
150- mid	39	35
- bottom	37	35
300 – mid	36	35
- bottom	36	35
500 – mid	35	34
- bottom	35	34
1000- mid	34	34
- bottom	34	34
2000- mid	33.5	33.5
- bottom	33.5	33.5

*In-Pipe-Dilution Ratio = [Total flow – flow in to RO(mgd)]/50 mgd RO concentrate

Table 6. Relative area estimates for different selected mid-water (= depth-averaged) (Mid) and bottom (B) salinity contours formed by the 127 and 253 mgd HBGS flow rates. (From Jenkins and Wasyl, 2004.)

Variable	**Coverage Area (Acres)***			
Flow rate (mgd)	**127**		**253**	
	B	**Mid**	**B**	**Mid**
Elevated Salinity Contour				
+1% (33.8°/oo)	1901	1512	591	434
+10% (36.8°/oo)	25	44	1	5
+4°/oo = 37.5°/oo)*	<12	39	<1	2

* Area calculations assume circular salinity contour
**EPA recommended salinity increase limit

data in Jenkins and Wasyl (2004). The reference salinities are +1% (33.8°/oo) and +10% (36.8°/oo), which are both standard indices used in discharge dispersion assessment, and 37.5°/oo, and the EPA (1986) recommended standard target level of ambient salinity + 4°/oo for minimizing biological effects related to salinity change. Table 6 demonstrates that very small salinity differences (i.e., nearly but not quite complete equilibration between the discharged and ambient waters) will persist over large areas. It also shows the effect of high flow rate that, by raising "in-pipe-dilution," decreases the size and salinity level within the elevated salinity zone. The estimated relative areas of these different salinity contours (Table 6) provide the most effective way of evaluating the potential biological effects of the salinity discharge, which will now be discussed.

4.0 Effects of the Combined HB Reverse Osmosis Desalination and HBGS Thermal Discharges

A suite of biological facts support the conclusion that increases in salinity modeled for the combined thermal and RO discharge will not be large enough to have a significant impact on the marine species or communities living near the HBGS. First, with respect to temperature, the MBC results show that the thermal increase currently experienced by the organisms living near the discharge is not affecting them or the marine community structure (MBC, 2001). The RO process will not affect the temperature of the HBGS discharge. Actually, because it dissipates most of the condenser-heated added to 100 mgd of seawater, the RO process will reduce the amount of HBGS heat that enters the ocean (Jenkins and Wasyl, 2004).

4.1 Environmental Salinity Effects and Organism Responses

The California Ocean Plan (SWRCB 2001) does not specify requirements or water quality objectives concerning the RO concentrate discharge. EPA (1986) policy on discharge effects related to salinity acknowledges that fishes and other aquatic organisms are naturally tolerant of a range of dissolved solids concentrations (in this case salinity) and must be able to do this in order to survive under natural conditions. Also, marine species do exhibit variation in their ability to tolerate salinity changes. EPA (1986) recommendations state that, to protect wildlife habitats, salinity variation from natural levels should not exceed 4‰ when natural salinity is between 13.5 and 35‰. Applied to the combined HBGS discharge modeled by Jenkins and Wasyl (2004), the depth-averaged and bottom salinities resulting from a 253 mgd flow would both become less than

37.5°/oo within 50 m of the core. In contrast, salinities under the 127 mgd flow rate would not reach this level until about 200 m from the core.

Figure 7 illustrates the mechanisms underlying the above-stated EPA principles governing the ability of marine organisms to tolerate salinity change (Graham, 2002). This graph plots a range of ocean salinities against the amount of salts (and organic solutes) in the body (tissues) of invertebrates and algae, fishes, mammals, and birds. The diagonal equality line indicates similar "ocean" and "organism" salinities. Marine invertebrates generally have about the same amounts of salts and other solutes in their tissues as are in the ocean. If the ocean salinity goes up or down the tissue solute levels of these organisms change in a similar way. Kelp also do this as do both zoo- and phytoplankton. All of these organisms are termed isosmotic (i.e., the "same" osmotic or solute content as seawater) and, because their tissue-solute levels change with seawater salinity, they are called "osmoconformers" (Graham, 2002). Fishes, birds, and mammals are different. They have about one-third the level of solutes in their body tissues as are in the ocean and they regulate this, thus maintaining about the same solute level over a range of ambient salinities. This is called "osmoregulation;" birds and mammals are more proficient osmoregulators than are fishes, however, most fishes tolerate a salinity range of several °/oo.

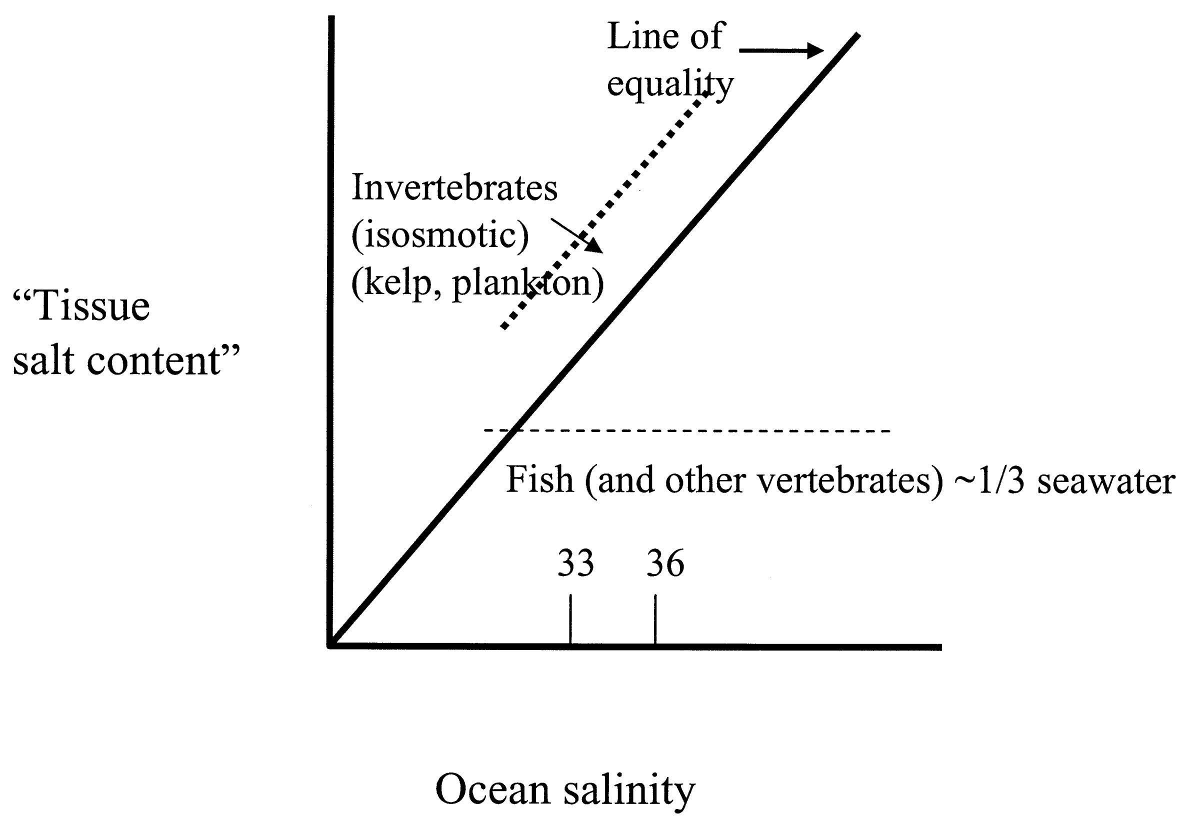


Figure 7. Salinity adaptation of marine invertebrates, fishes, and other organisms.

Most marine invertebrates and fishes become stressed if ambient salinity changes to levels beyond the range that they can make the appropriate adjustments (by osmoconformity or osmoregulation) and thus begins to affect body function (EPA, 1986; Graham, 2002).

4.2 The Natural Salinity Range Encountered by Marine Species Living at Huntington Beach: An Argument Based on Geographic Distribution

Most of the marine organisms living near the HBGS also occur throughout the SCB, including the areas where salinity is elevated (Soule and Oguri, 1974). Also, the natural geographic distributions of most of the species in Huntington Beach waters extend south to near the tip of Baja California. In this area both coastal temperatures and salinities are higher than those at Huntington Beach (Hickey, 1993) and approach levels modeled for most of the discharge field formed at 253 mgd and a large part of that formed at 127 mgd (Table 5). In addition, some of these species, or ones very closely related to them live in the upper part of the Gulf of California where salinities are 36-38°/oo and can be as high as 40°/oo (Brusca, 1980). Thus, many of the species living at Huntington Beach naturally experience and adapt to salinities in the range of those predicted for the combined HBGS discharge. (The only exception is the small ocean zone at the base of the discharge pipe and within about 50 m of the it at the 127 mgd HBGS flow rate where salinities will be higher than 40‰, Table 5.)

4.3 The Salinity Tolerance Limits of Marine Species Will Exceed Most Conditions Predicted for the Combined Discharge

Here are the lethal salinity concentrations (LC_{50}) of three different species (Pillard et al., 1999). (The LC_{50} is a statistically based method for estimating the lethal point of 50% of the group tested.)

Common name	Scientific name	LC_{50}	Test period
Mysid shrimp	*Mysidopsis bahia*	43	48 hours
Sheephead minnow	*Cyprinodon variegatus*	70	48 h
Silverside minnow	*Menidia beryllina*	44	48 h

These three species naturally occur in estuaries where salinity can be quite variable and this explains their high salinity tolerances. Note that 48 hours of exposure was needed for lethal salinity. Except for the inner core of the permanently elevated salinity zone that will prevail at 127 mgd flow (see Table 5 and below), these combined salinities and requisite exposure times far exceed the combined Huntington Beach RO Desalination and HBGS thermal discharge conditions modeled by Jenkins and Wasyl (2004).

What follows are salinity data for some marine organisms that are very similar to those living along the Huntington Beach coastline.

a. Invertebrates. Invertebrates are generally slow moving and most of them live on the bottom or within the substrate and will thus need to endure the permanent salinity increases that will result from RO operations.

1. Roundworms. Roundworms (nematodes), live in the marine sand and mud in the Huntington Beach area. Tests on four species from the English coastline showed that two of them *Axonolaimus paraspinosus* and *Sabatieria punctata*, both of which reside in the intertidal zone, could live in 2x seawater for 48 hours (Forster, 1998). The other two species (*Daptonemia oxycera* and *Cervonema tenuicaida*), which live in deeper water, had 10-20% mortality after 24 – 48 hours exposure to 2x seawater:

Species	Percentage of test group not surviving in 2x salinity after:				
	1	8	12	24	48 hours
A. paraspinosus	0	0	0	0	0
S. punctata	0	0	0	0	0
C. tenuicauda	0	0	0	10	10
D. oxycerca	0	0	10	20	20

The combined time and salinity extreme required to cause the mortality of some of the test animals (but, note that the 50% tolerance point, LC_{50}, was not reached for any of these worms) are much more severe than will occur in most of the area that will be contacted by the combined discharge from the RO facility and the HBGS.

2. An isopod. Isopods are very small, short-lived crustaceans that also live in marine substrates. Many adult females brood their young on their bodies. Isopods occur at Huntington Beach. A study of the Mediterranean isopod *Sphaeroma serratum* showed that 96 hours of continuous exposure to 55°/oo or higher was required for young isopods to die and that 96 hours at 70°/oo was required to cause adult mortality (Charmantier and Charmantier-Daures, 1994).

3. Mysid shrimps. Mysids are small shrimp-like crustaceans, also known as opossum shrimp because the female holds up to 60 developing young in her brood pouch. Mysids occur in SCB waters but there are no salinity tolerance data for them. However, tests with the Florida estuary mysid *Mysidopsis bahia,* show an LC_{50} of 43°/oo [(these are earlier shown data from Pillard et al. (1999)].

4. Hermit crab larvae. The species of hermit crab living on the Huntington Beach seabed is very closely related to *Pagurus criniticornis*. Tests on *P. criniticornis* done by Blaszkoski and Moreira (1986) show that, over the course of 16 days (at 30°C) its larvae grow and metamorphose equally well in 25 and 35°/oo, but at 45°/oo fewer larvae progress beyond stage II (about 5 days). Thus, chronic exposure lasting several days at

salinities much higher than those predicted for the Huntington Beach RO discharge are required to impede this hermit crab's larval development.

5. Other larvae and zooplankton. A model developed by Jenkins and Wasyl (2004) considered the extent that planktonic organisms (i.e., those that drift with the ocean currents) would be exposed to the high salinity conditions around the discharge. As illustrated by Figures 8A and B, organisms drifting through the discharge would experience elevated salinity for variable periods of time, depending upon both the flow scenario and organism position relative to the discharge core area. Under the 127 and 253 mgd flow regimes, exposure to the smaller inner core regions where salinity is highest would be an hour or less. Outer core salinities would be experienced for 2-3 hours. Times within the salt wedge would be longer, however, these salinities are only slightly above ambient.

b. Fishes. In contrast to most benthic invertebrates, most fishes are fairly mobile. They occur throughout the water column and also live on the bottom. Fish can sense temperature and salinity. They may swim into areas where temperature (and salinity) exceed preferred levels, spend a brief time, and then swim out. Thus, the mobility of fishes and their ability to sense and avoid localized conditions would be part of the natural behavioral responses expected for all fish species in all habitats, including the Huntington Beach discharge area.

How do fish salinity tolerances compare to the predicted conditions for Huntington Beach? Here are data for four species:

1. The sargo. A study of the sargo (*Anisotremus davidsonii*) by Brocksen and Cole (1972) and Lasker et al. (1972) showed:

- Optimal salinity for juvenile feeding and growth determined over 14 days is 33-45°/oo.
- Adverse effects on feeding and growth were seen at greater than 45°/oo (14 days).
- Salinities greater than 40°/oo adversely affect developing eggs and larvae after about 70 hours exposure.

2. The bairdiella croaker. Investigation of bairdiella, *Bairdiella icistia* (Brocksen and Cole, 1972; Lasker et al., 1972; May, 1974, 1975a,b) revealed the following facts:

- For juveniles, 14 day tests indicated the optimal salinity for feeding and growth is 33-37°/oo.
- Adverse effects begin at greater than 45°/oo (14 days).
- Salinities greater than 40°/oo adversely affect developing eggs and larvae after about 14 hours.

Lasker et al. (1972) further showed that bairdiella egg fertilization could occur normally up to $45^{o}/_{oo}$ and that 24-hour development proceeded normally in $48^{o}/_{oo}$ and proceeded normally for 72 hours in $45^{o}/_{oo}$.

3. Grunion. For the California grunion (*Leuresthes tenuis*) (Reynolds et al., 1976) determined:

- Prolarvae (i.e., larvae with a yolk sac, up to about 4 days old) have an upper salinity tolerance (LC_{50}) of $41^{o}/_{oo}$ after 24 hours exposure.
- 20-30 day old larvae tolerate a maximum of $40^{o}/_{oo}$ for about 18 hours.
- In these studies both test groups tolerated more extreme salinities for shorter periods.

4. Topsmelt. *Atherinops affinis* can be acclimated to live in $90^{o}/_{oo}$ (Carpelan, 1955).

In summary, these details about invertebrate and fish salinity tolerance show that for a diversity of organisms, including species that live in the Southern California Bight or are closely related to them, the extent of exposure: that is, the **magnitude** and **duration** required for a toxic salinity effect, exceeds in most cases (the exception being the zone around the core discharge at the 127 mgd flow scenario) the range of conditions that most marine organisms will experience in the Huntington Beach discharge field.

While comprehensive salinity tolerance information does not exist for all the species living in the Huntington Beach area, the available data indicate that the salinity tolerances of these animals will be far in excess of the salinity levels predicted for the combined RO (50 mgd) concentrate and thermal dispersion models. Thus, for marine organisms similar to those living at Huntington Beach, adverse salinity effects, including mortality require continuous exposure to salinities above about 40°/oo for 24-48 hours or longer. This means that at the prevailing HBGS flow regimes, organisms that either swim near or drift through the combined RO and HBGS thermal discharge will be unaffected by salinity fluctuations. Only bottom-dwelling animals living very close to the outfall pipe will be continuously exposed to the elevated, but variable salinity feature of the combined discharge. Within this small area bottom salinities above 40°/oo will not occur at 253 mgd flows and at the 127 mgd flow rate, the zone having a salinity of 40°/oo or greater will extend no more than about 50 m from the outflow (Table 5).

5.0 Bioassays With Product Water from the RO Demonstration Facility Now Operating at Carlsbad, CA

Since early 2003, Poseidon has operated a small (36,000 gallons per day) RO unit adjacent to the Encina Power Plant (Carlsbad, CA). This facility enables the testing of RO methods specific to the area and seawater. It has also been used in bioassay testing of marine organism responses to mixtures of the RO concentrate and seawater. Currently, a display aquarium at the site holds a variety of local marine species living continuously in a salinity of 36.2‰. Specimens in the tank include the barred sand bass, California halibut, red sea urchins, and green abalone.

California Ocean Plan toxicity requirements for RO discharge are also being met by using the demonstration facility's 2x concentrated seawater in tests with local marine species. Tests done for Poseidon by MEC Analytical Systems (Carlsbad, CA) used RO concentrated seawater diluted to a salinity of 36‰ in standard bioassays with three species.

1) *Macrocystis pyrifera*, giant kelp, germination and growth (48 hours).
2) *Atherinops affinis*, topsmelt, 7 day survival using 10-day old larva.
3) *Haliotis rufescens*, red abalone, embryonic development over 48 hours post fertilization.

Bioassay results are on file with Poseidon and MEC. They indicate no effect of RO-concentrated seawater in cases where it had been diluted to 36°/oo using local seawater. In cases where the 2x concentrate had been diluted to 36°/oo using distilled water, red abalone eggs failed to develop properly over 48 hours, implying that the relative amounts of different types of salts in the water were not balanced at the time of testing.

These findings largely agree with earlier bioassays done by Bay and Greenstein (1992/1993, a SCCWRP sponsored study) who investigated the toxicity of mixes of brine (obtained from a variety of sources) and seawater and other waters including secondary effluent wastewater. These workers conducted standard bioassays using giant kelp, amphipods, and fertilized sea urchin eggs.

- Their 48 hour test of spore germination and germ tube length using *Macrocystis pyrifera* indicated no effect of salinities ranging from 34.5 to 43°/oo.
- Hypersalinity tests with the amphipod *Rhepoxynius abronius* showed no effect on survival of 10 day exposure to salinities ranging from 34.5 to 38.5°/oo.
- Tests of sea urchin (*Strongylocentrotus purpuratus*) fertilization also showed no effect over 48 hours of various concentrations of

brine (from the RO facility at Diablo Canyon) and diluted with seawater.

It is very important to emphasize the latter finding on sea urchins and contrast it with other data presented in the same report. While Bay and Greenstein **did not find a hypersalinity effect** on sea urchin development when they used brine that had been diluted with seawater, they did find that brine diluted with 24-hour composite secondary effluent wastewater (El Estero treatment plant, Santa Barbara, CA) negatively affected fertilized sea urchin egg development. This brine + wastewater result has received considerable notoriety. It was cited with an expression of concern in the California Coastal Commission (1993) report on desalination. Opponents of desalination consider it to be a key scientific fact and evidence that sea urchins and other echinoderms cannot be successful in areas near desalination plants. As a group, the echinoderms (the Phylum Echinodermata (sea urchins, starfish, sand dollars, and sea cucumbers) are the only major marine taxa that does not extend into freshwater. Echinoderms are generally regarded as being less resistant to salinity change than other groups (actually, they are less resistant to seawater dilution but relatively tolerant of salinity increases). For example, the argument has been made that salinity will eliminate sand dollars from Huntington Beach and cause greater bacterial pollution. However, not only do sand dollars not consume sufficient numbers of water-dwelliing bacteria to affect bacterial numbers in the water-column, the bottom survey data reported by MBC documents that sand dollar occurrences at Huntington Beach and the surrounding areas are highly irregular.

It is unclear why the Bay and Greenstein finding of **"no brine + seawater hypersalinity effect on sea urchin development"** has gone relatively unnoticed in the same report.

- Their main conclusion is clearly stated: "Desalination plant brine and elevated salinity did not produce toxic effects on amphipods, kelp spores, or sea urchin fertilization."
- However, their report's conclusions focus more on the brine + sewage result: "Elevated salinity and sewage effluent had significant effects on sea urchin development…. "sea urchin embryos proved to be among the most sensitive of marine species." "More work also needs to be done on the interactions between sewage effluent and desalination waste brine."

It thus appears that the finding of **no effect of brine + sea water**, which is the relevant dilution model for Huntington Beach, has either been ignored or is not known. In either case, recent tests at the Poseidon desalination test facility again confirm no effect of RO brine + seawater on sea urchins. In studies contracted by Poseidon, Mr. S. Le Page (M-Rep Consulting, Carlsbad, CA) has successfully maintained sexually mature spiny sea urchins (*Stronglyocentrotus purpuratus*) for 3 months in 36.2°/oo (range 35.7-36.4°/oo) seawater blended from demonstration plant RO water and seawater. In addition, Le Page has successfully fertilized sea urchin eggs in 36°/oo seawater (60 minute sperm activation tests). Additional laboratory testing of the long-term survival of different species in higher salinities and other bioassays are currently in progress at the Encina RO facility.

6.0 Ecological Monitoring of RO Discharge Effects at Antigua

Appendix 1 reports a study sponsored by agencies in the State of Florida that sought to conduct preliminary field studies of the effect of RO discharge on marine organisms. A team of scientists from several state and federal agencies and universities searched for a location where they could manipulate an RO discharge to conduct a "before and after study." They found an ideal situation on the Caribbean Island of Antigua where a small 1.8 mgd RO unit was operating. This plant was discharging its RO concentrate into a storm drain that emptied onto rocks and crossed a short beach before entering a large lagoon (or at high tide flowed directly into lagoon water).

The team secured permission from plant operators to connect the RO discharge to an extension pipe that would transport the concentrated seawater to a further-offshore position in the lagoon where flow from the previous RO discharge siting had not reached. The selected area contained living coral and a diversity of algae, macroinvertebrates, and fishes. By conducting observations before and for six months following the pipe's installation, these workers concluded there were no effects of the direct discharge of 1.8 mgd of seawater concentrate ($57^{o}/_{oo}$) into the study area.

7.0 Summary: Biological Significance of the Combined Huntington Beach RO Desalination and the HBGS Heated Discharge

This report finds that the combined RO concentrate (50 mgd) and heated discharge from the HBGS will not have a significant biological effect on the Huntington Beach benthic or pelagic habitats. This finding is based on a detailed review of the modeling analyses conducted by Jenkins and Wasyl (2004) and the coupling of this modeling with the time-series biological monitoring data obtained for the Huntington Beach marine community near the HBGS discharge since the early 1970s by MBC Applied

Enviornmental Sciences. Added to this is information from the scientific literature about the salinity tolerances of marine organisms including species the either live in the Huntington Beach area or within the Southern California Bight or are ecologically similar to species living there. All of this information strongly infers that the salinities that will prevail over most of the discharge area and in particular the elevated salinity zones near the discharge, will in most but not all cases be within the tolerance ranges of the species residing there. For example, most of the organisms living along the Huntington Beach coastline also occur in areas of the Southern California Bight where salinity can be greater (e.g., in San Pedro Bay) than will occur in most of the combined discharge receiving water area. Also, the natural geographic distributions of most of the Huntington Beach resident species extend south to near the tip of Baja California where both coastal temperatures and salinities are as high or higher than those modeled for the combined discharge. In addition, some of these species, or ones very closely related to them live in the upper part of the Gulf of California where salinities are 36-38‰ and can be as high as 40‰.

The modeling studies clearly establish that a zone of elevated salinity will form around the discharge and that both this zone's area and its salinity elevation above ambient (33.5‰) will be determined by the HBGS's total cooling-water flow rate, which affects "in-pipe dilution ratio" of the 2x seawater RO concentrate (Table 5). The 20-year operational history of HBGS shows that "average" (253 mgd) and "low" (127 mgd) flows each account for nearly 50% of the HBGS's total flow rate. Modeling these two flow cases shows that elevated bottom and depth-averaged salinity zones will occur 50-150 m out from the discharge. At both flow rates high salinities occur at the core but rapidly dissipate with distance and quickly reduce to levels that will not have biologically significant effects on either the benthic or pelagic organisms it touches.

The Jenkins and Wasyl (2004) models show that beyond 300 m and out to 2,000 m (1.2 miles), there will only be minor differences in the bottom and depth-averaged salinities resulting from the 127 or 253 mgd flows. Moreover, the special circumstance of a zero delta T that was modeled for the 127 mgd (simulating HBGS standby mode) shows only a very slight salinity increase (+1°/oo) over the entire dispersion field compared to that for the 127 mgd heated discharge.

The dispersal models for both flows therefore focus the environmental-effect question on the zones of occurrence of elevated salinity; that is (and see Tables 5 and 6) the areas in which either depth-averaged or bottom salinity is above about 38°/oo. For organisms occurring in the water column (i.e., plankton, some macroinvertebrates, fishes, turtles, mammals, birds) of these areas, the duration of the elevated salinity exposure will vary with their location and residence time in the zone. Assuming, conservatively, that a fish or squid that is 6 inches long has an average swimming speed of about 0.17 mph [this would be about one-half of its body length every second (Maddock et al., 1994)], then this animal would require about 2.0 hours to swim across the maximum diameter of the 127 mgd salinity zone (about 600 m = 0.35 miles). Half of this swimming-time would be in salinities less than 39°/oo, and the total time of exposure to salinities above 43°/oo would be about 1 hour. A larger fish or squid would swim much faster, as would a turtle or dolphin, which are much larger in size. Such a brief exposure time to elevated salinity would have no effect on marine mammals, turtles, or most fishes which are good osmoregulators, and, while most fishes are unlikely to prefer salinities this high, the salinity tolerance data reported here show they are unlikely to be adversely affected by high salinities for this brief period (i.e., adverse effects of >40°/oo require exposure times of 24 hours or longer). Also, fishes would be able to "sense" such a marked salinity change and could alter their swimming direction to avoid it.

In the case of plankton that drift across the elevated salinity areas, Jenkins and Wasyl (2004) showed these would experience elevated salinity for variable periods of time depending upon both the area of the zone and its salinity, and the drifting organism's rate of movement and its position relative to the discharge core. Under both the 127 and 253 mgd flow regimes, exposure to the smaller inner core regions where salinity is highest would be an hour or less (Figure 8A and 8B). Outer core salinities would be experienced for 2-3 hours. Times within the salt wedge would be longer, however, these salinities are only slightly above ambient.

While plankton, fishes, and other water-column residents would have relatively brief exposures to the elevated salinity zones, this would not be the case for the benthic organisms occurring in these areas. Bottom-dwelling organisms at the core would experience a salinity of between 48‰ (at 127 mgd) and 39‰ (253 mgd). Salinity decreases abruptly with distance, reaching 37‰ at 150 m in the case of the 127 mgd flow and reaching 36‰ at 50 m in the case of the 253 mgd flow. Tolerance data for several bottom-dwelling species (e.g., roundworms live in 2x seawater, isopods tolerate 55‰, mysids 43‰, hermit crab larvae up to 45‰) suggest that a salinity up to 38‰ and even higher could be tolerated. Thus, the major salinity zone effect for the benthic organisms near the discharge core might be a reduction in overall species diversity, coupled perhaps with an increase in

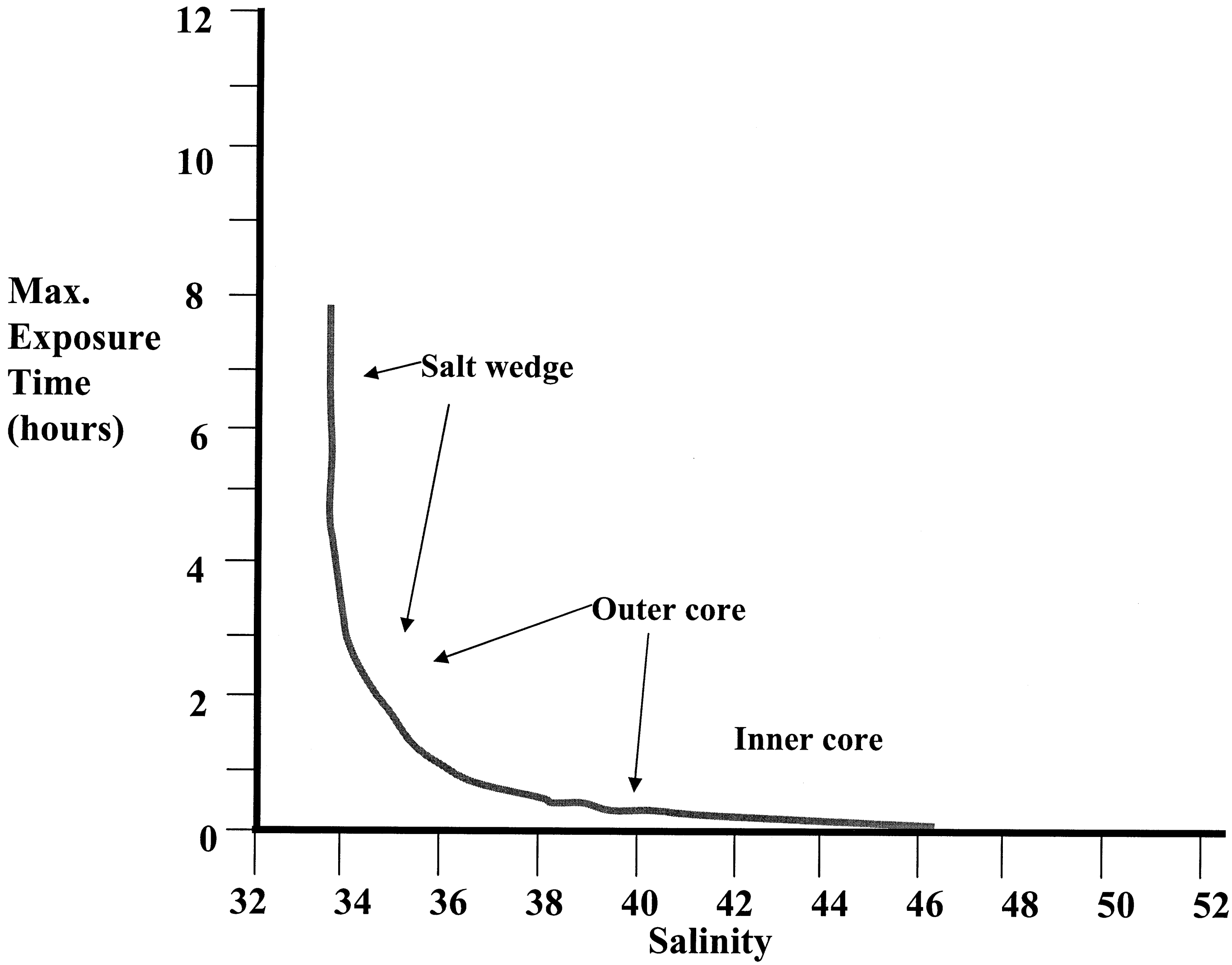


Figure 8A. Residence time in different salinities for organisms drifting through the 253 mgd flow field. Time in the high salinity inner core is very short compared to drift time in the salt wedge (Jenkins and Wasyl, 2004).

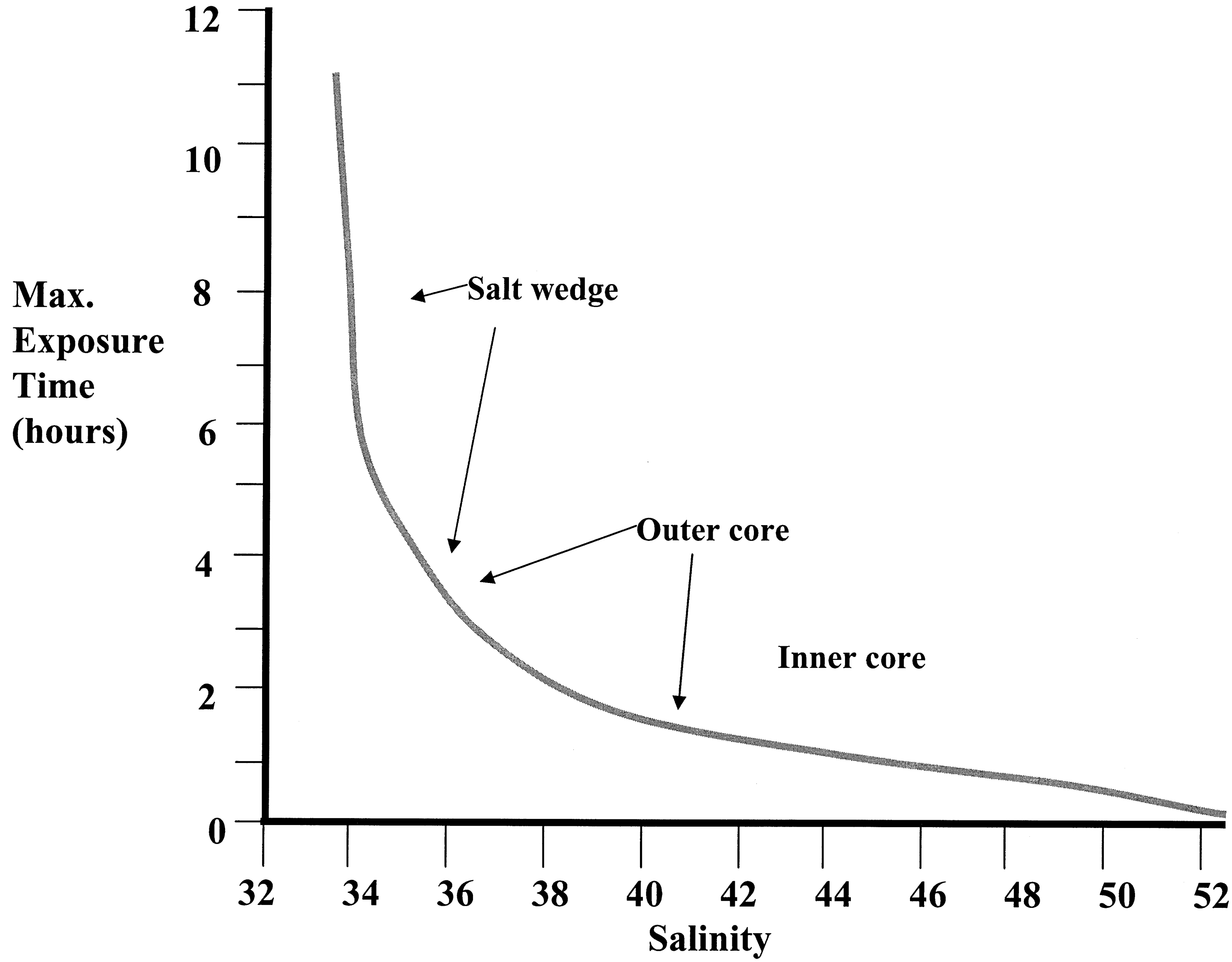


Figure 8B. Residence time in different salinities for organisms drifting through the 127 mgd flow field. Inner core salinity higher than for 253 mgd flow, but drift time in inner core is very short compared to drift time in the salt wedge (Jenkins and Wasyl, 2004).

the abundances the species that can live successfully in the elevated salinity regime.

The modeling results indicate that the area of the elevated salinity zone will depend upon HBGS cooling-water flow rate. While 127 and 253 mgd described HBGS flow history over the past 20 years, since HBGS renovations were completed in 2002, the average flow rate (from 2002 to July 2003) was 265 mgd. This elevated flow rate will further reduce the area of the elevated salinity zone.

Finally, two additional facts bolstering the "expected non-effect" of the combined RO and HBGS discharge come from observations made with small RO facilities. A small RO demonstration facility at Carlsbad, CA has been used for "salinity tests" confirming previous assessments showing that standardized salinity bioassays with kelp, a larval invertebrate, and a larval fish indicate no effect of prolonged exposure to 36°/oo. Indeed, a diversity of Encina species (many of which also live at Huntington Beach) live perfectly well in a small aquarium with a 36°/oo salinity.

Studies in Antigua provide additional evidence supporting the conclusion that there will be no discharge-salinity effect. A field study sponsored by the State of Florida was conducted there to assess RO discharge effects on corals and other organisms living in a tropical reef lagoon. Observations before and for 6 months following the introduction of the discharge of 1.8 mgd of undiluted (57°/oo) RO concentrate indicated no effect on either the organisms living around the point source or those that came into the area.

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APPENDIX 1
DESALINATION DISCHARGE STUDIES AT ANTIGUA

Summary and Analysis of:

"Effects of the Disposal of Seawater Desalination Discharges on Near Shore Benthic Communities"

Introduction

This is a review of the scientific and technical information contained in "*Effects of the Disposal of Seawater Desalination Discharges on Near Shore Benthic Communities*," a draft report, dated 1 April 1998, that was authored by Mark A. Hammond, Norman J. Blake, Craig W. Dye, Pamela Hallock-Muller, Mark E. Luther, David A. Tomasko, and Gabe Vargo.

The combined expertise of these authors is in the areas of marine biology, marine and coastal ecology, coastal engineering, and environmental science. Many of them have a professional association with the report's sponsoring agencies: Southwest Florida Water Management District and the University of South Florida.

The report describes research evaluating the biological and other effects of the concentrated seawater discharge from a Reverse Osmosis (RO) seawater desalination facility located on the Caribbean Island of Antigua. This research was a fundamental aspect of the environmental pre-planning studies conducted prior to construction of a high capacity RO plant at Tampa Bay, Florida.

What is in this Report?

It describes results of a field reconnaissance of apparent biological and other effects resulting from discharge of the concentrated saline water by-product from the Culligan Enerserve RO desalination plant operating on the Caribbean Island of Antigua. Antigua, which is in the Lesser Antilles Island chain of the West Indies, is located about 300 miles south-southeast of Puerto Rico.

RO Plant Specifications

Located on Antigua's eastern shore along Crabbs Peninsula and adjacent to Parham Harbor, the Culligan Enerserve RO plant has been operating since 1993. It has a freshwater production capacity of 1.32 million gallons per day (mgd) and uses Parham Harbor surface water [salinity 35 parts per thousand (ppt)] for its source water. The RO plant's by-product, about 1.8 mgd of concentrated (57 ppt) seawater, is discharged into Parham Harbor.

These specifications, in addition to a discharge area that contains a healthy and diverse biological community (with many similarities to Tampa Bay) made the Antigua RO site a desirable study area. Also, and perhaps most important, the research team was able to manipulate the RO plant's discharge to suite the experimental objective of obtaining baseline data on a marine habitat's physical and biological status before and then during a period when it was exposed to the concentrated seawater discharge.

Since it began operation, the Antigua RO Plant has discharged its concentrated seawater by-product into Parham Harbor via an elevated rectangular concrete flume extending to the water's edge (Figure 1). Depending upon tidal height (daily range in Parham Harbor is 0.25 m), this discharge either spills directly into the water or flows to the water's edge across a 3-5 m strand of exposed beach and rock.

What experiment was done?

The authors of this study received permission to temporarily change the discharge site. By installing a plywood stopper and flange over the end of the flume and there attaching a length of 12 inch PVC pipe, the discharge point was extended 20 m (about 60 ft) out into Parham Harbor. Figure 1 shows the position of the discharge pipe relative to the RO plant and a large jetty. The pipe's end was capped and a discharge port was formed by cutting a 12x12 inch (0.3x0.3 m) saddle notch on the pipe's upper side.

Diversion of the discharge was done in March 1997. In the days (22-29 March) prior to the diversion, investigators conducted baseline, pre-salinity exposure studies of the habitat that would receive the concentrated discharge. The objectives were to census the study area and describe its water quality. It was necessary to establish that the site was biologically representative of the habitats and environmental conditions generally present in Parham Harbor. It was also important to confirm that the site was not contacted by the pre-existing RO shore-discharge plume.

Environmental effects of the newly established discharge site would be assessed by comparing the "pre-discharge" state with conditions found at three month (June 22-26) and six month (October 1-6, 1997) post-diversion site surveys.

How was the environmental survey conducted?

The discharge study area was mapped. Six linear transects, extending radially 10 m out from the center (=discharge site), and at 60 degree angles from one another, were marked at one- or two-meter increments using PVC stakes and tags. As seen in Figures 1 and 2, transect lines reflect compass headings and are numbered clockwise beginning nearest to North. Transects extended both on- and offshore from the discharge site. Transects II and IV were approximately parallel to the shoreline. Water depth at the discharge-pipe opening was about 1.2 m and the opening, a rectangular ($0.09 m^2$) notch on the pipe's upper surface, directed discharge up to contact water surface. Three transects extended offshore into moderately deeper water and three went into more shallow water. Maximum water depth at the termini of the three most near-shore transects ranged from 0.7 to 1.1 m. The depth range at the outer end of the three most offshore transects was from 0.8 to 2.6 m. Together, the six transects define a 20x20 m ($400 m^2$) area centered over the discharge-pipe opening. This study area was used to map topographical and other physical features as well as discharge-water contours.

Water quality was assessed using a Hydrolab system and by noting in particular the distribution of the three principal RO discharge "signals," increased temperature, lowered pH, and increased salinity. Monitoring was done on rising and falling tides and at different times of the day. Tidal current flows were recorded and dye was injected at the flume to observe discharge cohesiveness and distribution.

Figure 2 shows transect locations for the Hydrolab and biological sampling. The Parham Harbor study area contains a diverse assemblage of healthy marine organisms including sea grass (*Thalassia*), algae (*Dictyota*) hard (*Porites*) and soft (*Pseudoterogorgia*) corals, and an association of tropical microalgae, micro- and macro-invertebrates, and fishes. In addition to a census of the principal species in this community, the plan was to also compare the pre-diversion abundance and condition of these organisms with their status after three and six month's exposure to the concentrated seawater discharge.

Using SCUBA and snorkeling, transect surveys were done to both count individual organisms and map the distribution of sea grasses, algae, and epibenthic macro-invertebrates. Divers also took sea grass and algal samples for laboratory analysis. Substrate samples (mainly coral sand) were taken using core or "grab samplers" and small syringes (modified for coring by cutting off their tips) in order to determine the types and relative abundances of benthic microalgae (including diatoms), of benthic foraminifera (small amoeba-like single celled animals with calcareous shells), and of infaunal (i.e., living within the substrate) macro-invertebrates. Plastic settling plates (also termed fouling plates), were attached to the substrate along the transects. These plates are inert surfaces that enable censusing of the types and numbers of organisms that are recruited (i.e., planktonic plant spores or animal larvae that drift into the area, settle out of the plankton, attach to the plate and become established) over a specific period. Divers also recorded the presence of fishes and mobile invertebrates (i.e., starfish, anemones, snails) on the transects.

Collected samples were either frozen or preserved and returned to the laboratory. Substrate samples to be assayed for diatoms and foraminfera were immediately injected with a vital stain (Rose Bengal), which colored and preserved the tissues, thus making it possible to distinguish organisms living at the time of collection from their empty (dead) skeletons. In the laboratory, samples were analyzed microscopically to assess the growth status of sea grass, to count and classify the diatoms and foraminifera (and differentiating the living and dead) and enumerate and classify the infaunal macro-invertebrates. Measurement of the substrate content of the photosynthetic pigment chlorophyll a was used as a proxy estimate of substrate microalgae concentration.

What are the Report's findings?

A. Physical conditions.

Pre-diversion water samples confirmed that water from the RO shore plume did not flow into the study area. Three features of the RO discharge water, elevated temperature and salinity and a reduced pH, were all detectable within the study area. The small differences between discharge and ambient water (discharge water was 2-3°C warmer and its pH was 0.2-0.3 units lower) were rapidly dissipated by mixing. Dye injected at the flume demonstrated the discharge plume's tendency for rapid dissipation and for movement towards deeper water (because it is denser it sinks). Depending upon bottom topography and contour and current flow, divergent pH and temperature values were rarely detected beyond 2-6 m from the discharge-pipe opening.

The large difference between discharge and ambient salinity (57 vs 35 ppt) resulted in a stronger salinity "signal," which was detectable beyond the 10 m study area and distributed mainly down slope. Maximum bottom salinities, recorded in the immediate vicinity of the discharge opening, were 35-40 ppt in June and 34-38 ppt in October. Because the pipe discharge flowed upward and contacted the surface, surface salinities were higher (35-

44 ppt June, 34-43 ppt October). However, and because of strong mixing, salinities at the 8-10 m transect positions averaged only 0.2 ppt above ambient, with salinity increases extending farther down slope than up slope.

B. Biological status.

Studies of the sea grass beds indicated no changes in their health (as reflected in the number of "new shoots"), abundance (biomass) and growth rate (productivity) over the three survey periods. There was thus no effect of concentrated saline exposure. Also, the levels of salinity measured in the study area are well below the levels (about 70 ppt) known to cause permanent cell damage to sea grass. All sea grass plants studied in all transects showed a high degree of parrotfish bite scarring which indicated that this foraging fish frequented the study area in spite of the concentrated salinity discharge.

Algal abundance was generally variable over the three sampling periods, however, this variation is not correlated with the discharge salinity. One brown alga (*Dictyota*) did show variations in its growth rate and a weak correlation was found for its growth rate and salinity. Tissues from plants living within the study area also showed a higher concentration of nitrogen than did plants sampled from outside the study area. Reciprocal transplant studies, in which *Dictyota* specimens from within the study area were moved out and plants living outside were moved in, failed to induce a nitrogen increase in the newly introduced study area residents and there is thus not conclusive evidence for a discharge-salinity effect on *Dictyota.* It was concluded that perhaps episodic chemical imbalances associated with excessive rainwater runoff (storm culverts flow into the flume and surface runoff mixes with the RO discharge) or possibly caused by either RO membrane servicing or RO system flushing may have affected the chemistry of *Dictyota*.

A greater concentration of substrate-dwelling microalgae (as indicated by greater chlorophyll a amounts) was found in June and October compared to March. However, because there was no trend within or along the transects, this suggested that a factor other than the saline discharge had triggered the microalgae concentration increase. Diatom numbers and types did not change from pre-diversion conditions in either sampling period or along any transect.

Benthic foraminifera occurred on all substrates including sea grass blades. Their distribution and abundance varied considerably within the study area, however, comparison of the pre- and post-diversion surveys showed no differences that related to the presence of the concentrated seawater discharge. Also, because foraminifera are considered reliable indicators of habitat health state, the absence of pre- and post-diversion changes for this group suggests the habitat was not stressed.

The benthic invertebrate infauna collections totaled nearly 37,000 individuals, distributed among 339 different kinds (taxa), that included sponges, coelenterates, annelid worms, mollusks, arthropods, peanut worms, echinoderms, and chordates (tunicates). Of the 339 taxa about 10 species accounted for 52% of the infauna. These dominant organisms included seven species of annelids and one species of snail. However, there were significant differences in the infaunal assemblage (i.e., both the absolute numbers and relative abundance of the dominant species) at different times. The March and October samples each had more animals than did the June sample. These differences in infaunal invertebrate abundance and diversity did not appear affected by elevated salinity.

The June and October settling plates documented the arrival of nearly 1800 individual animals representing 12 different taxa. Bryozoans and polycheate (annelid) worms were the dominant forms with hydroids, snails, clams, and sea urchins also settling. A large influx of hydroids occurred in June but not in October. However, overall variations in the groups that settled on the plates at the different sampling times was attributed more to biological factors (reproductive season, productivity, etc.) than an elevated salinity effect. Because there was no pre-diversion settling plate data, it is unknown whether or not increased salinity excluded any species from settling.

Benthic macro-invertebrates observed by divers in the study area included hard (*Porites*) and soft (*Pseudoterogorgia*) corals, the great anemone (*Condylactus*), the cushion starfish (*Oreaster*), and the queen conch (*Strombus*). *Porites* colonies living near the discharge pipe in salinities about 5 ppt above ambient survived the entire study period. The mobile macro-invertebrates such as *Strombus* and *Oreaster* were frequently observed in close proximity to the discharge pipe.

Thirteen species of fish were recorded in the study area. The two most abundant species were the bucktooth parrotfish (*Sparisoma*) and the yellowtail snapper (*Ocyurus*). More species occurred in a deeper part of the study area, about 6-10 m away from the discharge site, where there was more rocks and greater vertical relief. There were no obvious or statistically significant effects of the saline discharge on either the macro-invertebrates or fishes in the study area or among the different observation periods. Both the fishes and mobile invertebrates appeared to move through the area independent of the salinity discharge profile. Parrotfish tooth scars on the sea grass plants in the study area confirm the regular appearance of this species.

What are the Report's Main Conclusions?

- The RO concentrate is rapidly dispersed and dissipated and salinity returned to ambient within a small distance of the discharge.

- There was not a salinity "build-up."

- The discharge area over which pH and temperature differ from ambient was much smaller than that of salinity.

- Study area transect surveys done before and then three and six months after diversion showed no discernable effect of RO discharge on the density, biomass, or productivity of the seagrass. Also, the number of seagrass shoot densities, an index of plant health and viability, did not differ before and six months after discharge diversion.

- The discharge had no effect on the feeding behavior of a major seagrass forager, the bucktooth parrotfish.

- The discharge had no effect on the abundance or the apparent health status (as indexed by chlorophyll concentration) of the benthic microalgae.

- Neither the abundance nor the diversity of the substrate-occurring diatoms was affected by the concentrate discharge.

- Benthic foraminifera were similarly unaffected by six month's exposure to the concentrated seawater discharge.

- Foraminifera are generally considered indicators of environmental quality. If the types and relative abundances of foraminifera in the study area did not change, this implies the salinity discharge was not having a large effect.

- Adverse responses to the seawater concentrate discharge, by either large invertebrates or fishes, were not observed by divers. Transect data similarly indicated no area-avoidance behavior.

- Divers commonly observed two mobile invertebrates, the queen conch and the cushion starfish within the areas of maximum salinity.

- Coral heads located within the transect area and exposed to an average salinity elevation of 4.5 ppt showed no ill effects over the entire 6 month observation period.

- Settling plates indicated the recruitment of a number of species into the area over the course of this study.

- The presence of both starfish and sea urchins in the elevated salinity study area is notable in light of the general perception that these animals (and all echinoderms) have a low tolerance for seawater salinity change.

What are the Report's most positive features?

- An experiment was conducted in which it was possible to evaluate a habitat before and after introduction of a concentrated seawater discharge from an RO plant.

- The team of expert scientists assembled for this study made careful observations of the "pre-" and "post-diversion" effects. They planned and executed a detailed sampling program to quantify the physical factors in the habitat and the response of the biota (in terms of both community structure and the relative abundances of major species) to the concentrated seawater incursion.

What are the Report's limitations?

- The sampling periods were limited to only two post-diversion observations and extended only six months post-diversion.

- This period is too short to determine how other variables such as season, rainfall, and nutrient presence and annual nutrient cycles, and biological cycles of recruitment and production influence the Parham Harbor marine community.

- Rains, for example, occur mainly in two seasons of each year (January-February) and (September-October), and a longer study period would be needed to assess this effect.

- The time limitation is further illustrated by the fact that the settling plate studies reported did not have "pre-diversion" control data. Plates gathered in June reflected study area colonization since March. Those collected in October indicated the combined settling history of six months. However, no plates were available to show recruitment between October and March and therefore a contrast between pre- and post-diversion settling cannot be made.

- Monitoring of a second "control" site, where no salinity changes occurred, would have provided important baseline data for interpretation of the possible causes of some of the small biological changes recorded within the study area.

What relevance does this Report have for proposed operations at Huntington Beach?

A. Reference Information.

1. The Antigua report reviews existing literature pertaining to RO discharge effects on marine biota, pointing out that very little is known.

2. Most of what is known is contained in technical reports and, for this reason, is not as directly accessible as data appearing in the more widely distributed journals.

B. The finding of no salinity effect.

1. The Antigua report provides a diverse number of broadly based observations documenting the lack of an effect of a rather large salinity anomaly on a tropical reef community.

2. "No effect" has also been predicted for the Huntington RO discharge which will be less extreme, in terms of the salinity differences between the discharge and ambient water, than Antigua.

C. Differences in the Antigua and Huntington RO plant and discharge systems.

1. The Antigua concentrate flows directly into the ocean (57→35 ppt).

2. The Huntington Beach concentrate will mix with Power-plant cooling water and become highly diluted before entering the ocean. At an average operating level of 253 mgd, the "in pipe" dilution ratio is (253-100 mgd)/50 mgd = 4, which means that 57 ppt will be diluted toward 39 ppt before the discharge reaches the ocean.

3. Both Antigua and Huntington Beach have upward directed, surface contacting discharges, which promotes rapid water mixing.

4. The Huntington Beach discharge volume (at least 200-400 mgd with 50 mgd of RO water) greatly exceeds that at Antigua (1.8 mgd). Not only does the "in-pipe" dilution ratio minimize the salinity effect on the environment, because of tidal and coastal currents there is a much

greater volume of open and moving water surrounding the Huntington discharge which will further enhance the plume dissipation.

D. Biological contrasts for Antigua and Huntington Beach

1. Antigua is tropical. Huntington Beach is not.

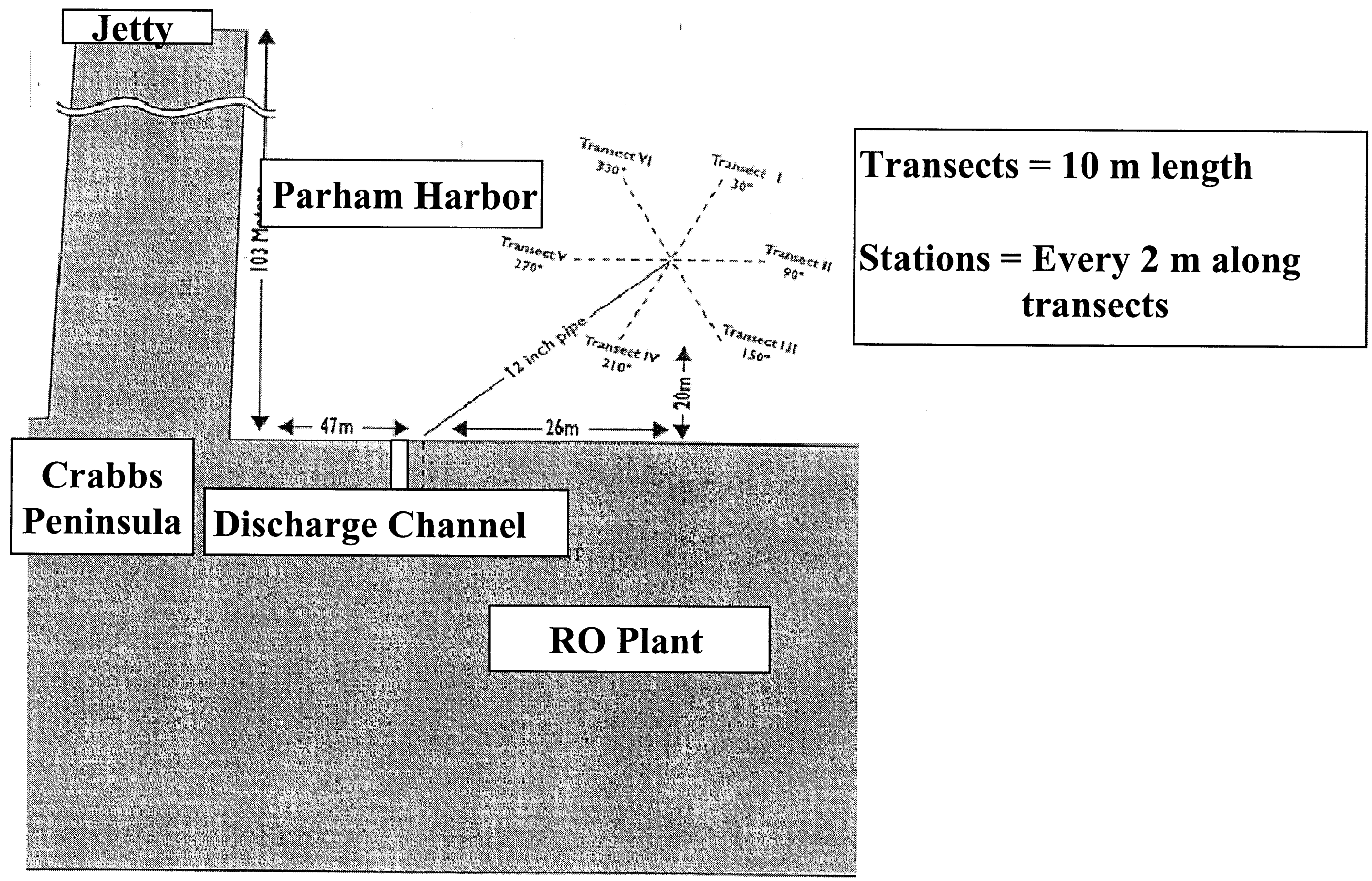
2. The Antigua Parham Harbor reef study area is complex having rocks and a notable vertical relief and a large benthic species diversity including corals, sea grass, and algae.

3. The area around the Huntington cooling discharge is a flat sand and mud surface. It is structurally less complex, having less vertical relief and having no corals or sea grasses and very little if any benthic algae.

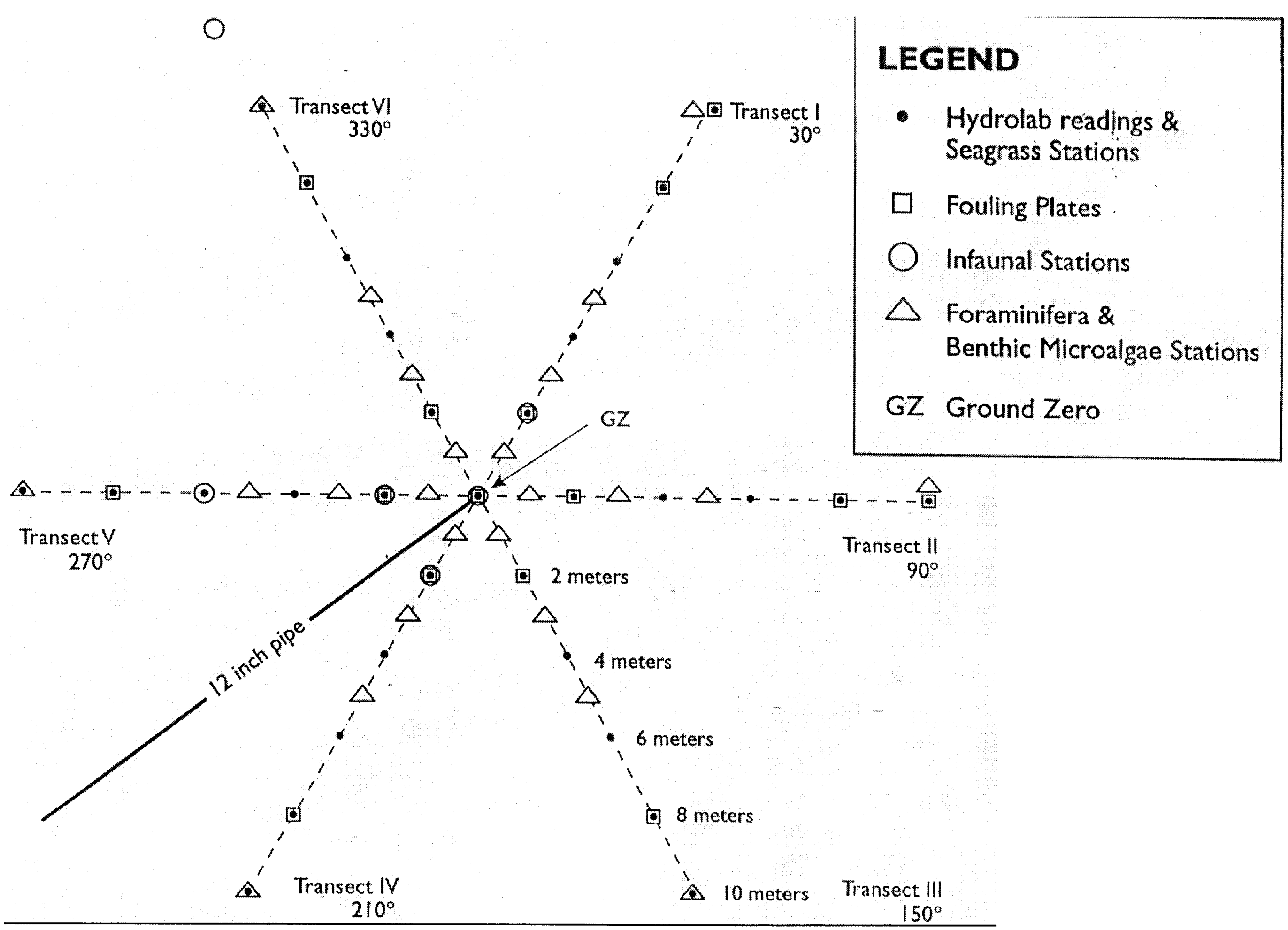
4. Because the sandy and mud bottom around the Huntington discharge lacks complexity there is a much lower abundance of benthic macro-invertebrates.

5. The infaunal diversity at Antigua and at Huntington Beach is expected to compare favorably, however, the species list for the two habitats would differ considerably if not entirely.

6. As has been documented for the Antigua study area, it is expected that macro-invertebrates and fishes that enter the seawater concentrate discharge area will not be affected by it and will not purposely avoid the area.



Appendix 1. Figure 1. Positions of the study area, the discharge channel, the pipe extension, and the radial transect area.



Appendix 1. Figure 2. Sampling details for the radial transects.

Biological Implications of a "Stand Alone" Operational Mode for the Desalination Plant At Huntington Beach, CA

12 February, 2010

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Executive Summary

In 2005, the Re-Circulated Environmental Impact Report (REIR) for a 50 million gallon per day (mgd) reverse osmosis (RO) desalination plant at Huntington Beach, CA was approved. This plant is co-located with the Huntington Beach Generating Station (HBGS), which will provide the source water for RO from the large volume of seawater pumped to cool its condensers. After passing through the condensers, about 100 mgd of this heated seawater will be withdrawn into the RO plant and processed to form approximately 50 mgd of potable water and about 50 mgd of doubly concentrated (salinity = 67 parts per thousand, ppt) seawater byproduct. The latter will be added back to the cooling water stream exiting the power plant enroute to the ocean-discharge site.

The HBGS fully compliments the RO operation, providing both the source water and, through excess flow, contributing to the "in pipe" dilution of the concentrate before it is discharged, thereby lessening the potential environmental effects of elevated salinity in the receiving-water habitat. The use of cooling water to dilute the concentrate before it is discharged into the ocean is an important advantage for co-locating desalination with a power plant and adds flexibility in planning for the handling of the discharge operation. Due to the many different variables existing at each desalination facility, the manner in which the discharge is processed must always be done on a case-by-case basis.

It is highly probable that, for the foreseeable future, co-location will continue to be the operational mode at Huntington Beach. However, because future operations could possibly involve the long-term reduction or no seawater discharge from the power plant, this report analyzes the potential impacts to the marine environment associated with a "stand alone" operational scenario for desalination at Huntington Beach, that is, in the absence of the power plant's discharge of a high volume of heated seawater.

Jenkins and Wasyl (2006, revised 2010) developed a hydrodynamic discharge model for the stand alone operation by the Huntington Beach desalination plant. The model's assumptions are:

1. Seawater intake pumps will deliver a flow rate of 152 mgd.
2. Normal desalination operations (i.e., 100 mgd intake, 50 mgd potable water, 50 mgd of seawater concentrate with 67 ppt salinity), with 52 mgd of seawater dilution.
3. The receiving-water conditions for mixing with the discharge were modeled at two different mixing rates:

a) The average rate of ocean mixing determined by integrating long-term conditions (i.e., the mixing strength due to mean values of the mixing-forcing conditions such as winds, waves, and currents; average mixing occurs about 50% of the time).

b) The worst-case conditions for ocean-mixing (probability occurrence 0.04% to 0.1%.

Model results were evaluated by comparing the effects of different ocean-mixing levels on the area of the discharge plume encompassed by the 40 ppt salinity contours. Use of the 40 ppt contour as a reference point is based on findings, reported in the approved REIR, Appendix S (Graham 2004) and in Le Page (2004, 2005) that long-term exposure to salinities higher than 40 ppt may adversely affect many marine species.

The models show that stand-alone desalination operations at a total flow of 152 mgd will result in the formation of a very small area of elevated salinity around the discharge tower and that this area will be affected by ocean-mixing conditions. The approximately 1:1 ratio for "in-pipe" dilution of the concentrated seawater stream reduces its salinity from about 67 to 49.9 ppt at the point of discharge and further dilution by the receiving water begins immediately upon contact.

Under both average and worst-case mixing conditions the maximum salinity occurring in the water column is about 49.4 ppt. The maximum salinity occurring on the bottom next to the base of the discharge tower is 41.0 ppt during average mixing conditions and 44.2 ppt under worst-case mixing conditions. Both water-column and bottom salinities decrease with distance and ultimately equilibrate with ambient salinity (33.5 ppt). During worst-case mixing conditions (occurring less than 0.1%) the perimeter of the 40 ppt contour on the seabed occurs 100 ft out from the base of the discharge tower and the contour's area is 0.72 acres. Under average mixing conditions (occurring 50% of the time) there is a smaller average distance from the base of the discharge tower to the 40 ppt contour (about 54 ft) and the seabed area covered by this contour is 0.21 acres.

The major difference between stand alone and co-located desalination operations at Huntington Beach is the smaller total flow rate occurring during stand alone, which causes less "in pipe" dilution and a higher discharge salinity and results in the formation of the small area of elevated salinity defined by the 40 ppt contour.

The principal biological effects of stand alone operation will occur within the small area of the 40 ppt contour. It can be expected that this very small area will undergo a decrease in the total number of organisms living there and perhaps also a reduced biodiversity. The replacement of some of the species living there now by other more salinity tolerant species is also a possibility. With respect to fishes and other pelagic organisms contacting the high salinity waters within the 40 ppt contour, these will either swim or "drift" (e.g., plankton) through the area in 1.4 hours, a relatively short time. (with average mixing conditions the shore-parallel maximum diameter of this contour would be approximately 100 ft) and this will lessen the effect of high-salinity exposure. Concerning the benthic organisms living outside the contour but within the area where the salinity gradient undergoes rapid dilution from 40 ppt down to ambient (33.5 ppt), these may become adapted to these salinity conditions and remain in the area, or species having a greater tolerance for variable salinity may move into the area. This will be determined by the effects of water mixing and currents on variability in salinity and exposure times these organisms experience.

It is emphasized that the elevated salinity area formed by stand alone desalination is very small. It will have an average area of 0.21 acres 50% of the time and would only rarely increase to 0.72acres. The area around the Huntington Beach discharge where this salinity elevation will occur contains no threatened or endangered species and the area itself is not designated an Area of Special Biological Significance. Further, the very small area of elevated salinity formed by stand alone desalination is extremely small relative to the vast expanse of the contiguous and biologically homogeneous area occupied by the sand-mud bottom community that extends several kilometers up- and down-coast from the Huntington Beach discharge. Also, the benthic species living in the discharge area are part of broadly distributed populations that extend throughout the coastal waters of Southern California, in most cases to as far north as Point Conception, CA as well as south into Baja California, Mexico.

Introduction

In 2005 the City of Huntington Beach, CA approved the Re-Circulated Environmental Impact Report (REIR) for a 50 million gallon per day (mgd) seawater reverse osmosis (RO) desalination plant to be co-located at the Huntington Beach Generating Station (HBGS). The title of this REIR is "Recirculated Environmental impact Report on the Seawater Desalination Project at Huntington Beach," and it will be hereafter referred to as REIR 2005.

This report analyzes what marine environmental effects would be associated with the operation of the Huntington Beach Desalination Plant as a stand alone facility, that is, without the HBGS providing a high volume of heated water discharge that dilutes the seawater concentrate. Stand alone operation would become necessary if the power plant changed from using all or a large portion of the once-through cooling for its condensers.

While there are no plans to alter the co-location operational status at Huntington Beach, it is clear from information presented in REIR 2005 that the HBGS is compatible with the Huntington Beach desalination plant. In addition to supplying the RO source water via its once-through cooling system, the concentrated seawater byproduct of RO is diluted by mixing with the cooling-water effluent before both are discharged into the ocean.

For this reason the requirement of a stand alone desalination operation would alter the concentration and distribution of the discharge.

A hydrodynamic modeling study of the dispersal and dilution of the discharge from the stand alone desalination plant was developed by Jenkins and Wasyl (2006, revised 2/2010). The objective of this report is to evaluate the biological significance of their findings.

The Model

The stand-alone model assumptions are:

1. Pumps would supply a flow of 152 mgd.
2. Normal operation of the desalination plant [withdrawal of 100 mgd of seawater to form 50 mgd of product water and 50 mgd of concentrated seawater byproduct (67 ppt salinity), and 52 mgd of seawater for dilution].
3. In-pipe dilution of the concentrate would be done on an approximately 1:1 ratio and result in an end of pipe salinity of 49.9 ppt.
4. The receiving-water conditions affecting its mixing rate with the discharge (i.e., temperature, salinity, tides, waves, currents, wind) would result in either:

a) average mixing conditions, as determined by integration of time-series for the variables affecting mixing, and which occur 50% of the time, or

b) worst-case mixing conditions, which has the probability of occurrence of 0.04% to 0.1%.

Modeling results were evaluated by comparing the areas of the average and worst-case discharge plumes encompassed by the 40 ppt contour (i.e., the area having salinity levels of 40 ppt or higher). The 40 ppt contour criterion is based on findings showing that long-term exposure to salinities 40 ppt or higher may negatively affect some marine species (REIR 2005, Appendix S, Le Page, 2004, 2005). Also, the hydrodynamic dispersal models developed at higher flow rates and reported in REIR 2005 used the 40 ppt threshold as a targeted boundary.

Findings

The stand alone operational models show that a protracted period of low flow (152 mgd) in the presence of either average or worst-case mixing conditions results in the formation of a small area of elevated salinity around the discharge tower. The approximately 1:1"in-pipe" dilution of the concentrated seawater stream reduces its salinity from about 67 to 49.9 ppt at the point of discharge. Further dilution by the receiving water begins immediately upon contact and an elevated salinity plume will form and extend outward and mainly down current from the discharge site. However, because the more saline water sinks, the highest plume salinities always occur on the seabed. This plume's shape and salinity will be a function of the rate of ocean mixing with the receiving water and with distance the plume and ambient salinities will equilibrate (REIR 2005).

Under both average and worst-case mixing conditions the maximum salinity occurring in the water column is 49.4 ppt. However, the maximum salinity occurring on the bottom next to the base of the discharge tower is 41.0 ppt during average mixing conditions and 44.2 ppt under worst-case mixing conditions. During worst-case mixing conditions (0.04% to 0.1% occurrence probability) the average distance from the discharge to the 40 ppt seabed contour will be 100 ft and the area of the seabed covered by the 40 ppt salinity will be 0.72 acres. Under average mixing conditions (50% occurrence probability) there is a smaller average distance from the discharge tower to the 40 ppt contour (54 ft) and the seabed area covered by this contour is 0.21 acres.

Operational Differences: Stand Alone vs Co-location

Co-location of the desalination and power plants at Huntington Beach allows use of a larger volume of heated cooling water to obtain a greater dilution of the seawater concentrate (REIR 2005 Appendix C). Under the stand alone operation, the hydrodynamic model shows that a 152 mgd flow rate with cold water will result in an extremely small area of elevated salinity, defined by the 40 ppt contour, around the discharge.

Biological Implications

Insofar as the biological community living within the 40 ppt salinity contour is concerned, the long-term benthic salinity gradient that prevails within the area will influence the kinds of organisms occurring there. The permanent salinity increase could likely affect either the abundance of some species or even the area's total species diversity. Within this area the result could be a less diverse community and the replacement of some of the species living there now by species that can be ecologically successful (i.e., feed, grow, and reproduce) there because they are normally adapted to habitats having higher salinities (e.g., euryhaline organisms typically found in estuaries). While there certainly will not be a “dead zone” around the discharge, it is possible that the numbers, diversity, and species types occurring in this very small area will change and the area may have only a limited number of macro-organisms.

With respect to fishes and other pelagic organisms that come into contact with the concentrated salinity area within the 40 ppt contour in the water column, these would either swim or “drift” (e.g., plankton) through this small (about 100 ft along shore, Jenkins and Wasyl, 2006, revised 2/2010) area in a relatively short period of time, which will minimize their exposure to the elevated salinity and thus lessen its effect. For the benthic organisms living outside the 40 ppt contour, but still within the small zone where salinity undergoes dilution from 40 ppt down to 33.5 ppt (ambient), these may, depending on the variability of salinity and exposure time, become adapted to the fluctuating salinity conditions and remain in the area. Alternatively, euryhaline species having a greater salinity tolerance may move into the area.

When considered on a larger scale, the ecological effects of the stand-alone discharge will be insignificant for several reasons. First, the seabed area having this high salinity is less than 1 acre, even under worst-case ocean mixing conditions. Second, no threatened or endangered species inhabit the area which is also not designated by the State of California as an Area of Special Biological Significance. Third, the area of the 40 ppt contour is very small relative to the vast expanse of the contiguous and biologically homogeneous seabed occupied by the sand-mud bottom community in the area; this extends for many kilometers up- and down-coast from the Huntington Beach discharge. Finally, all of the species occurring in the discharge area are part of broadly distributed, continuous populations occurring throughout the coastal waters of Southern California, in most cases to as far north as Point Conception, CA as well as south into Baja California, Mexico. These distributional features of the organisms occurring around the Huntington Beach discharge ensure that stand alone effects will be localized.

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